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Safety Implications of Onboard Refueling Vapor Recovery Systems

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FINAL REPORT

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Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Sources
Office of Air and Radiation
U. S. Environmental Protection Agency

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This report evaluates the safety implications of requiring onboard refueling vapor recovery systems on gasoline-powered passenger cars, light trucks and heavy-duty vehicles. Special attention is given to the analysis of the design considerations for a safe onboard system and other measures necessary to insure that the design considerations incorporated are capable of providing a high level of in-use fuel system integrity.

Concerns over the potential safety implications of onboard systems have been raised. These concerns can be grouped into four general areas. These include requirements to pass the National Highway Traffic Safety Administration (NHTSA) safety test, the effects of tampering and system defects, refueling operations, and in-use fuel system safety.

All of these concerns are presented as well as design considerations for a safe system. In use fuel system safety is also presented as well as cost and leadtime considerations for implementating a safe system.

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I. Executive Summary

The purpose of this technical report is to evaluate the safety implications of requiring onboard refueling vapor recovery systems on gasoline-powered passenger cars, light trucks and heavy-duty vehicles. In that light, special attention is given to the analysis of the design considerations for a safe onboard system and the other measures necessary to insure that the design considerations incorporated are capable of providing a high level of in-use fuel system integrity.

Onboard refueling systems are in many ways similar to present fuel tank evaporative emission systems. The emissions emanate from the same location on the vehicle and the basic technology used to control the two types of emissions is quite similar. Many of the components are analogous, if not essentially identical, and the configuration/layout of the systems on the vehicle is also expected to be about the same. In fact, these two systems and system functions are so similar that many manufacturers will likely combine their onboard refueling and fuel tank evaporative emission systems into one integrated system which can serve both purposes. The fact that these systems are similar and will be integrated has two effects on the safety of onboard systems. First, many of the approaches and techniques used to safely implement evaporative emission control systems can also be applied to insure the safe implementation of an integrated onboard refueling/evaporative emission system. Second, any safety problems related to integrated onboard/evaporative systems should be evaluated incremental to present evaporative systems. Quite simply, there is no need to add a whole new system to the vehicle.

Concerns over the potential safety implications of onboard systems have, however, been raised. These concerns can be grouped into four general areas. These include requirements to pass the National Highway Traffic Safety Administration (NHTSA) safety tests, the effects of tampering and system defects, refueling operations, and in-use fuel system safety.

Concerns with the design requirements necessary to comply with the NHTSA safety tests focused on the need to integrate an onboard system into a vehicle in a manner which would provide the crashworthiness and rollover protection demanded by Federal Motor Vehicle Safety Standard (FMVSS) 301. EPA's analysis indicates that crashworthiness for the key vapor lines and other system components could be accomplished using many of the same approaches and techniques now applied successfully to evaporative emission systems. Further, the rollover protection now provided for the fuel tank through the use of a limiting orifice can be gained through the application of one of the several rollover valve designs now available.

Concerns have also been expressed that canister tampering and component defects could lead to in-use safety problems. While canister tampering is infrequent, the rate can be reduced and the potential safety effects eliminated through proper placement. Manufacturers are expected to consider the safety implications of tampering when evaluating canister location options on the vehicle as they do now with evaporative control system canisters. While the concern has been expressed that defects in onboard system components could have safety implications, no data or other bases have been found that suggest onboard systems would influence the nature or frequency of such occurrences as compared to those seen on current evaporative emission systems. In fact, given the experience gained by the manufacturers in safely implementing evaporative controls, it is likely that an integrated onboard/evaporative system could be implemented with no more (and perhaps less) problems than present evaporative emissions systems.

Concerns over the safety of refueling operations are centered on the potential to overpressurize the fuel system. EPA's analysis finds that use of a liquid seal solves all overpressure problems, and that if a mechanical seal is used a simple pressure relief device can be used to eliminate any overpressure concerns. As discussed in the analysis, a few other less significant potential problems have very straightforward engineering solutions.

Finally, while it is clear that onboard-equipped vehicles can be designed to comply with FMVSS 301 requirements, there has been concern expressed that fuel system integrity in-use may decrease by some non-quantifiable amount because FMVSS 301 can't cover all potential accident situations and an onboard system requires modifications and additions to the present evaporative emission system. While no test procedure can cover all potential situations, it does not necessarily follow that system modifications or additions will cause an increase in risk over present systems.

Both vehicle and fuel system safety are evaluated as an integral part of the overall design and development process. This involves multiple trade-offs, balances, and compromises with other key design considerations. Given the need to consider all key design criteria, manufacturers accept or manage a certain amount of risk. Since the safety demands of Federal standards such as FMVSS 301 must be incorporated into vehicles/systems, these standards represent the minimum. In many cases the level of safety achieved in-use goes beyond that required by Federal standards, being driven by in-use liability concerns.

If a manufacturer perceives that the added risk mentioned above may exist for one or more of its vehicle models, there are ways to respond through direct measures or through keeping the overall risk in-use at acceptable levels through other design flexibilities. EPA's analysis identifies and describes a number of these measures. Manufacturers can make vehicles safer than they are now; an onboard requirement does not increase the amount of risk a manufacturer need incur or accept. Manufacturers are expected to integrate onboard controls into their fuel systems without compromising safety.

Further, as part of overall risk management, implementing onboard controls provides the opportunity to improve overall fuel handling and fuel system safety. Refueling spills will be reduced and flammable vapors will be trapped in the canister instead of being vented out the fillpipe near the nozzle operator where inadvertent ignition is possible. Also, installing rollover valves could improve the safety for those vehicles now using external fillpipe vent lines without rollover valves. The positive seal provided by a rollover valve is an improvement over the "controlled leak" rollover protection currently provided by a limiting orifice. In addition, implementing onboard systems could further enhance safety by providing the opportunity to make other safety related fuel systems changes which have been delayed for economic or other reasons (e.g., changing from rear to side fill). Finally, if a manufacturer chooses to use a collapsible fuel bladder to control refueling emissions, this would eliminate all of the potential concerns raised relative to the canister based onboard system, and would provide improvements in safety over the present fuel system.

Other key considerations include safety related costs and the leadtime needed to implement onboard controls safely. This analysis estimates that safety costs related to implementing onboard systems will range from $4.50-$9.00 per vehicle. While the cost estimates for the needed hardware, modifications and fuel consumption impacts are reasonably accurate, there is some uncertainty in the development and safety crash testing cost estimates. However, safety related onboard costs are quite insensitive to even large changes in the estimates for development and safety certification.

In a general sense, EPA's estimates are supported by the fact that the modifications needed for present vehicles to insure fuel system safety in-use have been acquired relatively inexpensively, and vehicles with evaporative emission systems comply with FMVSS 301 today. Much of the groundwork needed to implement an integrated onboard refueling/evaporative emission control system safely has been completed and many of the same techniques and approaches can be used. The fact that integrated systems will be used means that some costs incurred to implement evaporative emissions systems safely will not reoccur. EPA's analysis has adequately accounted for safety costs in its estimate of the total onboard system cost. Safety costs contribute about 25 percent of the $20 cost estimated for a passenger car onboard system.

With regard to leadtime, given the magnitude of the task and past experience with implementing evaporative emission and fuel system integrity standards (FMVSS 301), this analysis indicates that 24 months leadtime is adequate. However, EPA is committed to providing the leadtime needed to implement onboard controls safely and effectively, and is open to considering additional leadtime or a short phase-in of controls to assist manufacturers in dealing with problems on unique vehicle models.

Finally, the onboard systems which would be installed on HDGVs are quite similar to those expected for passenger cars and light trucks, even though the safety test requirements are different for HDGVs. With the exception of school buses, the fuel system integrity testing centers more on evaluation of fuel tank integrity than vehicle crash testing. Nevertheless, many of the concerns raised and addressed above regarding onboard safety for lighter-weight vehicles also apply to HDGVs and support the judgment that onboard systems can be applied safely to this class of vehicles within the leadtime laid out above and for a reasonable cost.

II. Introduction

EPA has received several comments from the Motor Vehicle Manufacturers Association, Automobile Importers of America (and their member companies), and the Insurance Institute for Highway Safety which have expressed various levels of concern about the potential safety implications of onboard vapor recovery systems.[1,2] Also, some preliminary comments regarding onboard safety have been received from NHTSA's technical staff.[3] The American Petroleum Institute (which has independently developed several onboard-equipped vehicles) and the Center for Auto Safety have expressed support for the implementation of onboard vapor recovery systems.[4,5] The purpose of this report is to discuss and analyze the safety related concerns raised regarding onboard vapor recovery systems.

Motor vehicle manufacturers face many difficult technical decisions in the design and development of vehicle systems and the integration of these systems into new vehicle models. The difficulty of these decisions often arises from the fact that this design, development and integration process requires the simultaneous consideration of a number of key criteria. One of the most important of these criteria, safety, is normally given a high priority in the design and integration process. However, the process also includes careful and prudent consideration of the trade-offs necessary to deal with other important criteria such as performance, reliability, cost, styling, and regulatory requirements such as fuel economy and emissions. In each case, manufacturers must find the appropriate balance of all the important criteria. Since the design of emission control systems has the potential to affect the overall safety of vehicles, EPA views safety as a primary concern when evaluating the feasibility of an emission control device.

EPA is presently evaluating the use of onboard vapor recovery systems (onboard systems) as a means of controlling refueling emissions. The potential safety implications of such controls require special consideration, because implementing onboard systems will involve some minor modifications of the vehicle fuel system. While safety influences all aspects of vehicle design, fuel system safety and integrity is a key concern in the design and integration process.

In evaluating the safety implications of requiring onboard controls, EPA has applied the philosophy that no increase in overall risk should be caused or accepted, beyond that now present with today's fuel/evaporative system. This applies to both compliance with the applicable Federal safety standards and the in-use safety of vehicles equipped with onboard systems. The following analysis will show that straight forward engineering solutions are available for all of the potential safety problems which have been identified, and that while final choices regarding exact system designs lie with the manufacturers, safe fuel system designs are achievable by all. This analysis of onboard safety issues and the associated cost and leadtime generally applies to any canister-based onboard system design. Further, as will be discussed below, this analysis indicates that it is quite possible that overall fuel system safety improvements could accompany the implementation of onboard controls.

The importance of evaluating the safety of onboard systems is highlighted by the Clean Air Act (Section 202 (a)(6)) which directs EPA to consult with the Department of Transportation (DOT) before requiring the use of onboard vapor recovery systems. This requirement is intended to insure that all safety issues have been properly identified and addressed. This report will also help to assist in the fulfillment of this requirement.

As outlined below, the remainder of this report is divided into five sections. The first section following this introduction (Section III), provides a general description of an onboard system to aid in the understanding of any related safety issues. Section IV summarizes and provides EPA's analysis of the comments received regarding the design of a safe onboard system, and Section V discusses onboard effects on in-use fuel system safety. Section VI discusses the effects safety considerations have on other important factors such as vehicle costs and leadtime. Heavy-duty gasoline-fueled vehicles (HDGV) pose similar yet distinct onboard control system safety issues, and Section VII addresses these similarities and differences. The final section provides conclusions.

III. Onboard Control System Description

Before considering any safety issues, it is important to have a clear understanding of onboard refueling vapor recovery systems (onboard systems) and how they work. Likewise, before considering the characteristics of the control system, it is important to understand the nature of refueling emissions. The purpose of this section is to provide the reader with both a clear understanding of what refueling emissions are and how onboard systems operate to control these emissions.

In many respects, onboard systems are similar to the evaporative emission control systems now in use on most gasoline-powered vehicles. In fact, it has been suggested that onboard systems are more an extension or modification of current evaporative emission systems than the implementation of a new control technology. An explanation of the differences and similarities between the two systems will provide a better understanding of the incremental nature of onboard systems relative to current evaporative systems, and will be useful in assessing the design, cost, and leadtime implications of implementing onboard controls safely, which are to be discussed later in the report.

This section will first briefly describe evaporative emissions and how they are currently controlled. Next, refueling emissions will be discussed and similarities between onboard systems and current evaporative emission systems will be presented. The section will end with a discussion of the differences between the two control systems.

A. Evaporative Emissions

Evaporative emissions emanate from two basic sources: the fuel tank and the fuel metering system (either a carburetor or fuel injectors). Evaporative emissions arising from the fuel tank are primarily "diurnal" emissions while those from the fuel metering system are termed "hot soak" emissions.* This analysis is primarily concerned with fuel tank evaporative or diurnal emissions since these emissions are currently controlled using an approach similar to that envisioned for an onboard system.

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* It should be noted that a small amount of hot soak emissions come from the fuel tank; the fuel tank evaporative control system would handle these as well as the diurnal emissions.

Diurnal evaporative emissions consist of gaseous hydrocarbons that are displaced from the tank when fuel in the tank is heated. Fuel heating can result from changes in ambient temperature or during vehicle operation due to the vehicle exhaust system and/or recirculation of fuel heated by the engine. In either case, as fuel in the tank and vapor above the fuel heat up, more of the liquid fuel evaporates, and the vapor itself expands, thus causing hydrocarbon vapor to be released into the atmosphere (unless captured by a control system). Fuel volatility, size of the vapor space, initial tank temperature, and the degree to which the tank is heated can all impact the quantity of hydrocarbons emitted. Diurnal emissions occur on at least a daily basis, and a system designed to control these emissions must be capable of handling repeated evaporative emission loads. Since the early 1970's, most vehicles have come equipped with a control system to limit the amount of diurnal evaporative emissions. The next section discusses the type of control system typically used on today's vehicles.

B. Evaporative Emission Control System

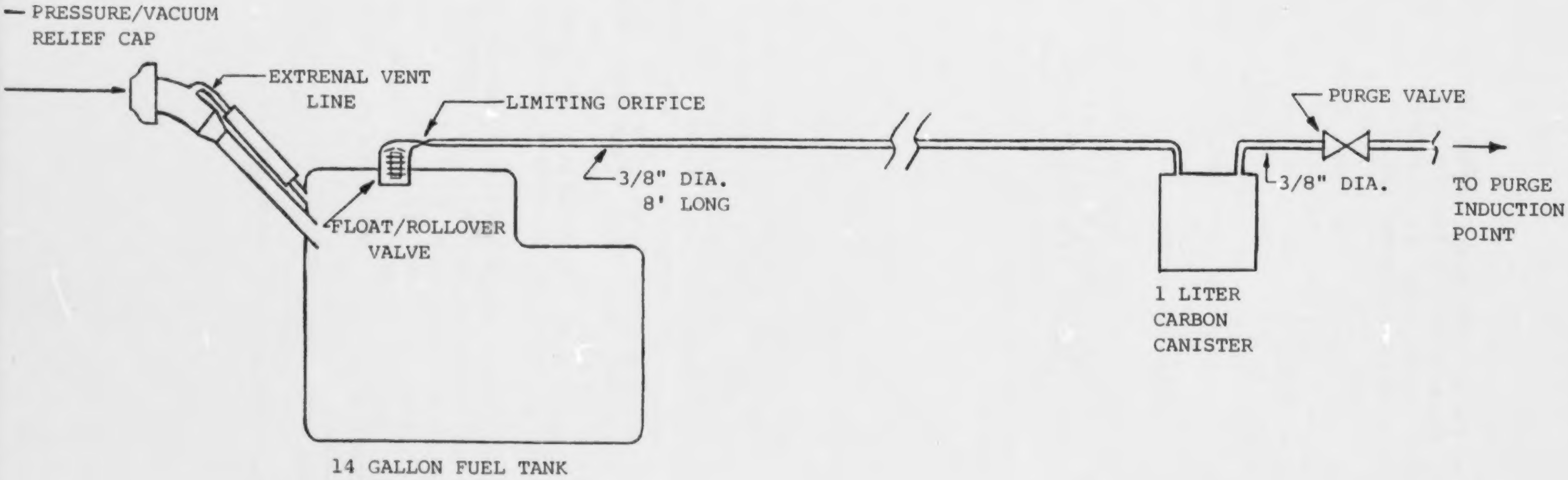
Figure 1 depicts a fuel tank equipped with an evaporative emission control system.[6] As can be seen from this figure, the control system is relatively simple in design and requires very few components. The purpose of this section is to describe each of the system's components in terms of both physical appearance and function.

In order to effectively prevent the escape of fuel tank vapors to the atmosphere, an evaporative control system must perform three basic functions. First, the system must limit the number of exits through which fuel tank vapors might escape. Second, the exit that does allow fuel tank vapors to escape must lead to a container where the vapors can be captured. Third, the system must eventually restore the capacity of the storage container by purging it of the trapped vapors. The discussion below describes how an evaporative emission system performs these three functions.

The first function an evaporative emission system must perform is to limit the outlets through which vapors can escape. As can be seen in Figure 1, there are only three openings through which vapors can pass: 1) the fillpipe opening, 2) the external vapor vent line to the fillpipe top (about 1/2" diameter), and 3) the small limiting orifice (approximately 0.050-0.055 inch) in the top of the tank. The fuel tank cap is designed to form a tight seal with the fillneck so that once the cap is secured in place, vapors from the fillpipe opening and the external vent line are trapped within the system. Thus, only one outlet exists through which fuel tank vapors can escape. This single available outlet is the small limiting orifice in the top of the tank.

Figure 1

Typical Current Evaporative System

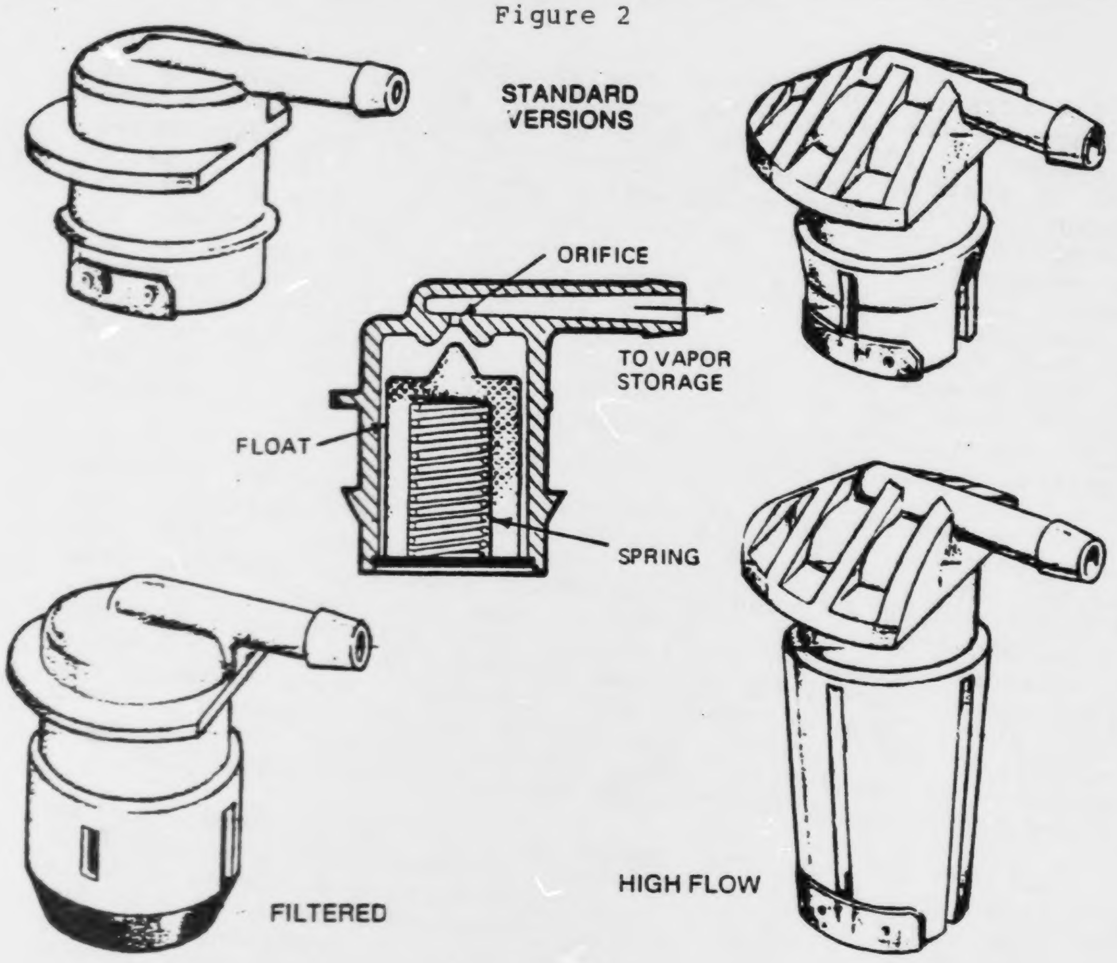

PRESSURE/VACUUM RELIEF CAP
EXTRENAL VENT LINE
LIMITING ORIFICE
FLOAT/ROLLOVER VALVE
3/8" DIA. 8' LONG
14 GALLON FUEL TANK
1 LITER CARBON CANISTER
PURGE VALVE
3/8" DIA.
TO PURGE INDUCTION POINT

As the tank undergoes temperature changes, and hydrocarbon vapors are generated, pressure builds up in the tank (as long as the fuel tank cap is secure in place). This pressure build-up is slowly relieved as gas tank vapors eventually force their way through the only available exit: the small limiting orifice in the top of the fuel tank which leads to the vapor storage device (charcoal canister). By limiting the number of vapor escape passages and routing the evaporative hydrocarbons to a single point, the control system has successfully performed the first of its three basic functions. Before discussing the evaporative emission system's second function, it is important to understand why the orifice in the top of the tank is so limited in size.

The orifice in the top of the tank is very small in size for three reasons. First, it allows pressure to build up in the tank when vapors are generated. This pressure build-up inhibits further evaporation and creates a pressure differential which eventually leads to hydrocarbon vapor being forced through the limiting orifice. Second, the limiting orifice acts as a liquid/vapor separator. If liquid gasoline were to splash up into the vent line leading to the evaporative emission control storage device (charcoal canister), damage could potentially occur to the storage media (charcoal). However, the orifice in the top of the tank is so small that liquid passes through it at only a very slow rate. Essentially only vapor is allowed to continue to the canister. This point leads to the final reason for limiting the size of the vent orifice to such an extent. Were the vehicle ever to be in a rollover accident, a very little amount of liquid fuel would be able to leak from the tank through such a small orifice. Thus, the limiting orifice is sized large enough to allow for adequate escape of evaporative emissions, but is small enough to permit only a slow leak from the fuel tank in the case of a vehicle rollover and thus provides the protection needed to comply with FMVSS 301. The cost for this is low. However, some manufacturers incorporate an additional valve for added protection; an example is shown in Figure 2.[7]

Storing the evaporative hydrocarbons is the second basic function an evaporative emission system must perform. Once the vapors escape from the fuel tank through the small limiting orifice, they proceed through a vent line (usually about 1/4"-3/8" inside diameter and made of some type of flexible rubber compound) that leads to a canister containing charcoal. The canister itself is usually made of plastic and is generally a cylindrical or rectangular container. Once inside the canister, the hydrocarbons are adsorbed onto activated charcoal where they are stored temporarily.

Figure 2



The tank mounted spring balanced float valve is a low cost unit designed for venting fuel tank vapor to the carbon canister. The device employs a float which remains open under normal conditions. Should the tank level reach a critical height, the float will close the canister vent line. In the event of extreme vehicle attitude or roll-over, the float will close the canister vent line.

A filtered tank mounted spring balanced float valve is available that performs the same functions as the above sketches except the tank side of the part is filtered to prevent contaminates from entering the part which might effect float closing of the canister vent line.

For high flow applications that require a large volume of vapor venting, such as fuel injection applications, a high flow valve has been developed that has more than twice the present flow capacity without loosing other critical performance parameters.

FLOAT VALVE

Borg-Warner Automotive, Inc.
707 Southside Dr., Decatur, Illinois 62525
Phone 217/428-4631

437
SKETCH
NUMBER

The working capacity of the charcoal, the quantity and frequency of the evaporative emissions, and the capability of the system to restore its working capacity all affect the amount of charcoal required. Current passenger car evaporative emission control systems typically utilize a 0.85-1.5 liter canister.[8] (This size is sufficient for both diurnal and hot soak evaporative emissions.) However, a finite amount of charcoal is used in the canister, so the storage capability of the canister is limited. Once the evaporative hydrocarbons have been adsorbed onto the charcoal in the storage canister, they will remain there until removed. The hydrocarbons must be stripped from the charcoal periodically in order to restore enough working capacity to adequately capture each successive evaporative emission load.

While the vehicle is operated, the evaporative emission system performs its third basic function of restoring the storage capability of the charcoal canister. After the vehicle's engine is running, manifold vacuum is used to draw hydrocarbon-free air through the charcoal canister. Hydrocarbons stored in the canister are desorbed into the air stream which flows into the fuel metering system via a flexible rubber purge line of about 3/8" diameter. Once purged, the evaporative hydrocarbons are burned as fuel through normal combustion in the engine. This process "empties" the canister, thereby preparing it for the next evaporative emission load.

One aspect of the purge process which needs to be mentioned but will not be explained in great detail is the fact that the canister is not continuously purged during vehicle operation.[8,9] A valve located between the canister and the fuel metering system is opened and closed at opportune times to control the purge process and limit disturbances which affect engine performance and exhaust emissions.

To summarize, the current evaporative emission control system performs three basic functions: 1) it limits the exits through which fuel tank vapors can escape; 2) it traps the vapors in a storage device; and 3) it restores the capacity of the storage device to prepare it for the next evaporative emission load.

Onboard systems are very similar to evaporative emission control systems because they must also effectively perform the same three basic functions to efficiently control refueling emissions. However, due to differences in the quantity of vapors and the rate of generation of evaporative and refueling emissions, equipping vehicles with onboard systems will require that some minor modifications be made to current fuel and evaporative emission control systems.

The next section provides additional detail regarding refueling emissions to help explain the fuel and evaporative system modifications that would be required to equip vehicles with onboard systems.

C. Refueling Emissions

Three processes contribute to the release of hydrocarbons during a refueling operation. The first two are collectively termed displacement losses, the third spillage. First, the hydrocarbon vapor present in the tank is displaced from the fuel tank by liquid fuel entering through the fillpipe. If the vehicle fuel tank is equipped with an external vapor vent line (as shown in Figure 1), much of the fuel tank vapor escapes via the external vent line which is connected to the top of the fillpipe. However, if no such vapor passage exists, the vapor makes its way out through the fillpipe concurrent to the incoming liquid fuel. Hydrocarbons are also generated and released during refueling as a result of liquid fuel evaporating as it is dispensed into the tank. This second type of displacement loss is caused by the turbulence in the liquid/air interface during the refueling process and is enhanced by the higher volatility of the dispensed fuel relative to the fuel in the tank. A third source of hydrocarbon refueling emissions is the evaporation of any liquid fuel spilled during the refueling operation. Of the three refueling emission sources, the two displacement sources are generally much greater (by far), unless a large spill occurs.

Because the bulk of refueling emission emanate from within the fuel system, refueling emissions are in many ways similar to diurnal evaporative emissions. Therefore, it follows that an effective onboard system can be designed which utilizes the same basic technology and approach utilized by current evaporative emission systems. In fact virtually all onboard systems considered by manufacturers in their comments incorporate this approach as do the prototype systems developed to date.[10,11,12,13,14,15] The similarities between onboard and evaporative emission systems are discussed below.

D. Onboard Refueling Control Systems

1. Similarities with Evaporative Emission Control Systems

In order to control refueling emissions, onboard systems must perform the same three basic functions as described previously for diurnal evaporative emission systems. These include limiting the number of exits through which refueling vapors can escape, storing refueling emissions temporarily in a charcoal canister, and purging the charcoal canister of the stored refueling vapors to restore its capacity prior to the next refueling operation. Because these three functions are so similar to the three functions a diurnal evaporative emission control system must perform and the emissions arise from the same location, extrapolation of known technology leads to the conclusion that an onboard system would use the same approach and similar hardware to that which is currently used to control evaporative emissions. Figures 3 and 4 depict two representative onboard systems and a comparison with Figure 1 shows that onboard controls are very similar in overall design to current diurnal evaporative emission control systems. However, while onboard systems do use many of the same basic components as evaporative systems, (i.e., charcoal canisters, flexible rubber tubing, purge control valve, etc.), the basic differences between refueling and evaporative emissions require a few additional components, and an enlargement of certain existing hardware is required for the onboard system. These are the key differences between the two systems.

Before discussing the component additions and enlargements, an important aspect of the onboard refueling vapor recovery system must be introduced.

Since both emissions emanate from the same location, a properly designed onboard system could control both refueling emissions and diurnal evaporative emissions. Thus, if an onboard refueling system were incorporated into a vehicle's fuel system, the current diurnal evaporative emission control system would no longer be needed. This aspect of onboard systems has several implications. First, it reduces the conceived degree of complexity the system adds to the vehicle's fuel system. An entirely new, larger, more complex system would not be needed in addition to that which currently exists. Rather, the current control system would be modified to be somewhat larger with a small increase in the number of components. Second, since onboard systems are basically modified evaporative emission systems, many of the safety design concerns associated with onboard systems have already been addressed in current evaporative emission control system designs. These approaches could also be used in the integrated system. One final effect a "dual function" control system has is it requires less "packaging" space and is less expensive to produce than two separate systems.

Figure 3

Integrated Evaporative/Refueling System

Nozzle Actuated Valve
Front Mounted Canister
Mechanical Seal

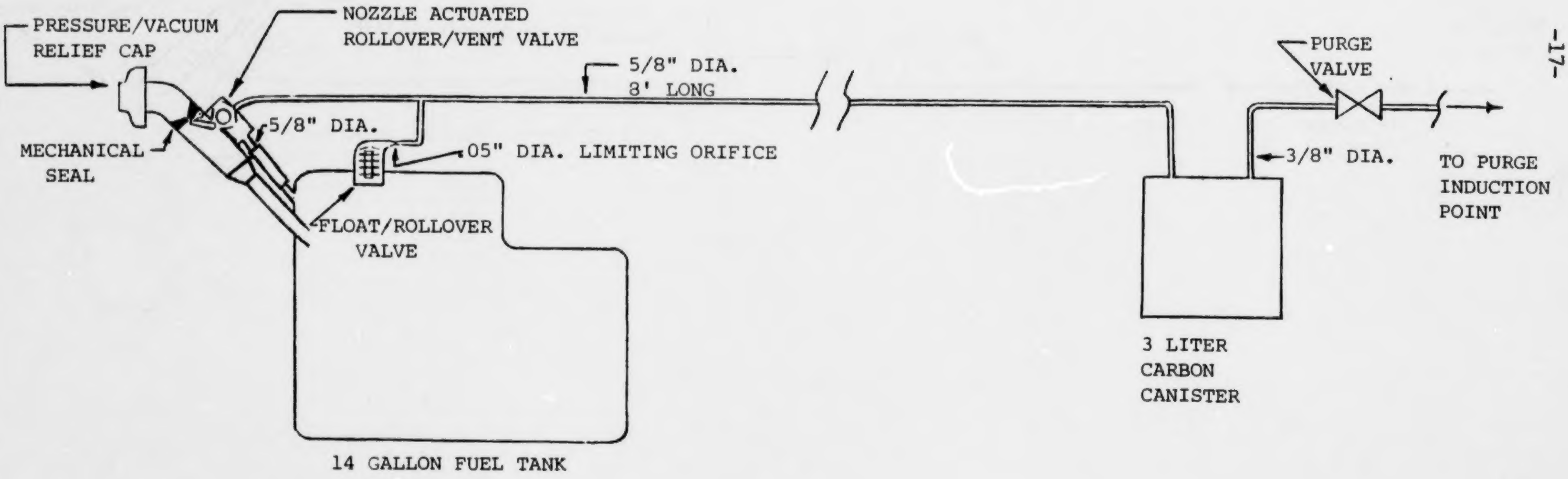
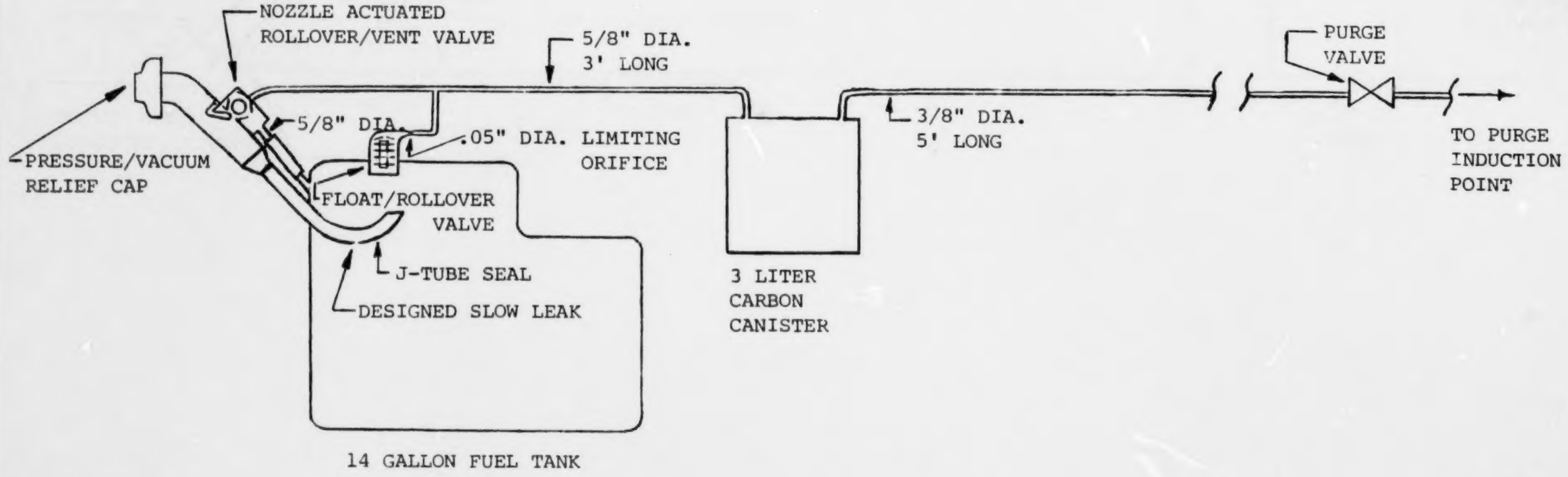

PRESSURE/VACUUM RELIEF CAP
NOZZLE ACTUATED ROLLOVER/VENT VALVE
5/8" DIA. 8' LONG
PURGE VALVE
MECHANICAL SEAL
5/8" DIA.
05" DIA. LIMITING ORIFICE
3/8" DIA.
TO PURGE INDUCTION POINT
FLOAT/ROLLOVER VALVE
3 LITER CARBON CANISTER
14 GALLON FUEL TANK

Figure 4

Integrated Evaporative/Refueling System

Tank Mounted Valves
Rear Mounted Canister
J-Tube Seal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.05" DIA. LIMITING ORIFICE
3/8" DIA. 5' LONG
TO PURGE INDUCTION POINT
FLOAT/ROLLOVER VALVE
J-TUBE SEAL
DESIGNED SLOW LEAK
3 LITER CARBON CANISTER
14 GALLON FUEL TANK

2. Additions/Modifications to Evaporative Emission Control Systems.

The differences between onboard systems and current diurnal evaporative emission control systems can be separated into two broad categories: 1) those related to the sealing of the system, and 2) those related to the magnitude and frequency of the refueling emissions. Because of these differences, onboard systems require several additional components, and several components of the current evaporative system must be increased in size or slightly modified.

a. Additions to the Present System

Diurnal evaporative emission control systems limit the number of vapor exits by using a fuel tank cap to close off the fillneck. However, during a refueling operation, the fuel tank cap is not in place, and consequently, onboard systems must rely on some other type of sealing mechanism to prevent the escape of vapor through the fillneck opening. Currently, two types of fillneck seals are available for use on onboard systems -- liquid and mechanical.

Liquid fillneck seals utilize modified fillpipe designs to route incoming gasoline in such a way that a column of gasoline is formed which prohibits the vapors in the fuel tank from escaping to the atmosphere via the fillneck. While this may sound somewhat complicated at first, the concept is fairly easy to understand with the help of a drawing. Several liquid seal configurations have been developed, but one design which has been shown to be particularly attractive from both a design and cost perspective is the "J-tube" (shown in Figure 5).[16] As fuel is dispensed into the fillneck, it is forced to pass through the "U" shaped portion of the fillpipe. A liquid trap is formed in the "U" shaped portion of the fillpipe which prevents vapors from escaping via the fillneck. The "J-tube" extension could be made of metal, plastic or hard rubber.

Another type of fillneck seal which has been shown to be effective is the mechanical type seal.[14,15] The mechanical type seal (see Figure 6) is basically an elastomeric device which forms a close connection with the inserted fuel nozzle and thereby eliminates any space in the fillneck opening through which vapor could escape. While both the liquid and mechanical type seals perform the same basic function of limiting the available vapor exits, the liquid type seal is inherently a simpler design.

Figure 5

J-Tube Liquid Seal

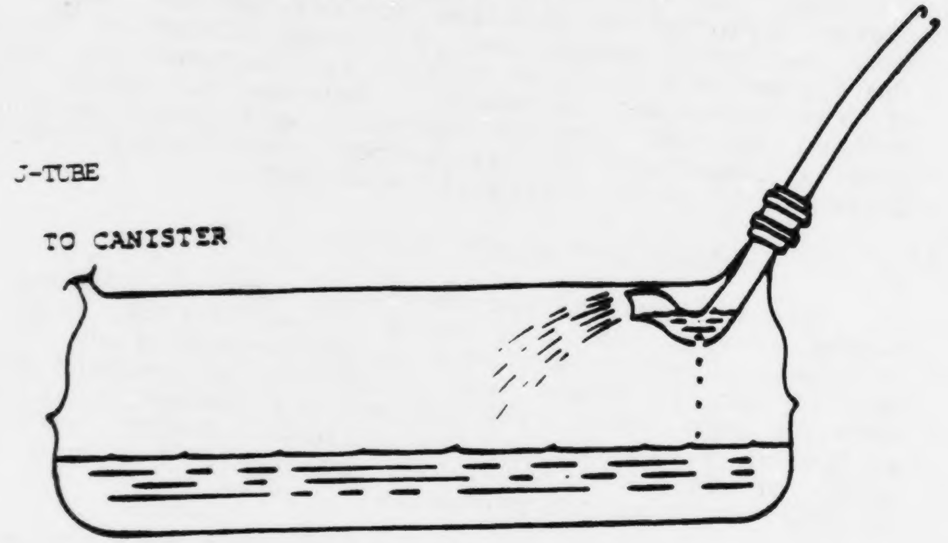
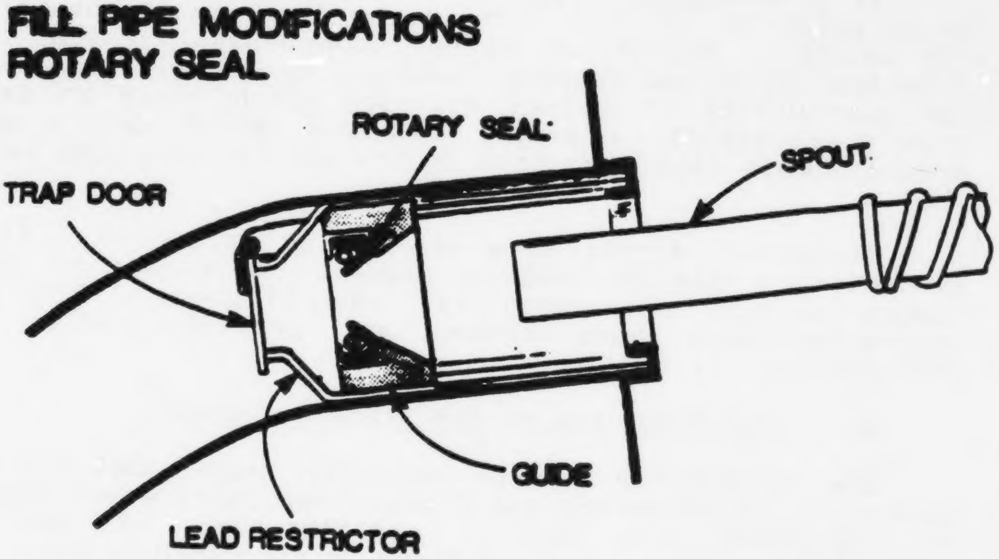
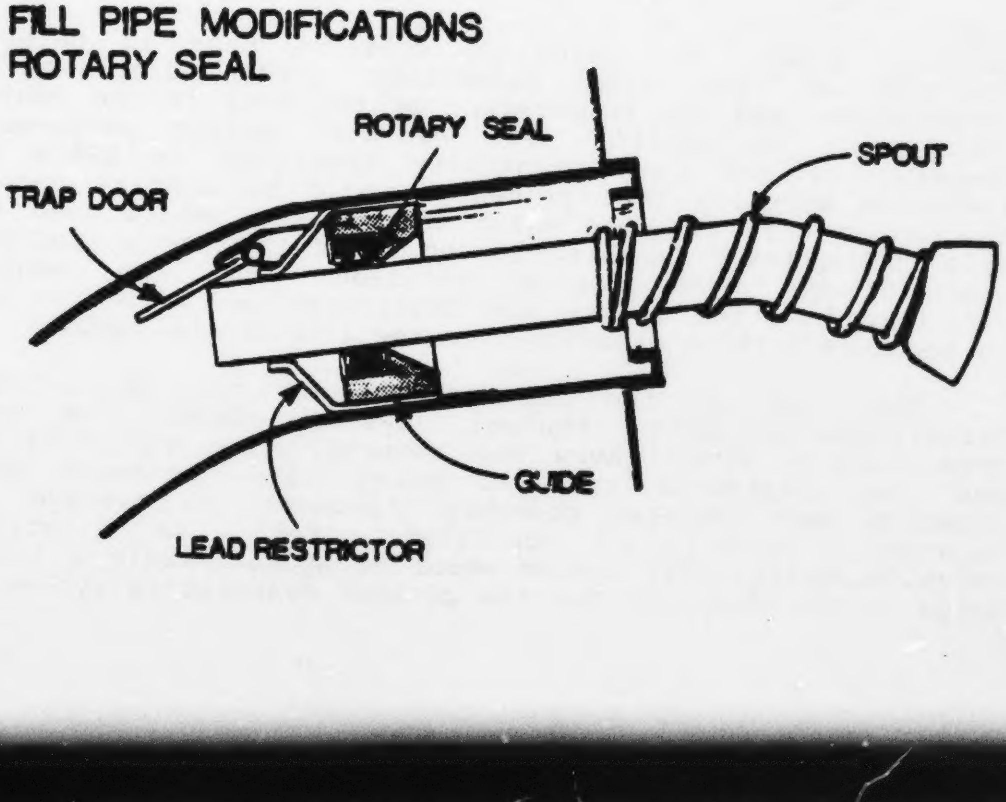

J-TUBE
TO CANISTER

Figure 6

Mechanical Seal


FILL PIPE MODIFICATIONS
ROTARY SEAL
ROTARY SEAL
SPOUT
TRAP DOOR
GUIDE
LEAD RESTRICTOR


FILL PIPE MODIFICATIONS
ROTARY SEAL
ROTARY SEAL
SPOUT
TRAP DOOR
GUIDE
LEAD RESTRICTOR

If a mechanical type seal were used, excessive pressure could build in the fuel tank if the fuel nozzle automatic shut off mechanism failed, or if for some unusual reason the vapor line leading to the charcoal canister became blocked. To avoid the possibility of a fuel spitback which could be caused by this overpressure, a simple pressure relief device would be needed. More detail on this device will be provided in Section IV.

Therefore, either type of sealing mechanism - liquid or mechanical - can be used to prevent the escape of refueling vapors to the atmosphere via the fillneck. Both sealing approaches have been tested and provide similar control efficiencies.[14,15]

b. Modifications to the Present System

The differences in the frequency, magnitude, and rate of generation of refueling and diurnal evaporative emissions leads to the need for several modifications to the present evaporative system. Each of these is discussed below.

(1) Charcoal Canister Size

Generally speaking, on a per event basis, refueling emissions are produced less frequently but are larger in magnitude than diurnal evaporative emissions. Consequently, more hydrocarbon storage capacity (larger charcoal canister) is needed to control refueling emissions than is needed for evaporative emissions.

For any given vehicle, the size of the canister needed depends primarily on the fuel tank volume and the refueling emission rate. The refueling emission rate is chiefly a function of the fuel volatility (RVP), dispensed fuel temperature, and the temperature of the fuel in the vehicle's tank prior to refill. For canister design purposes the temperatures and fuel volatility specified in EPA's draft refueling emission test procedure would be used to determine the design emission rate which the canister would need to be able to capture. Canister sizing would then be a function of tank volume, the design emission rate, as well as considerations for safety and deterioration factors to assure an adequate working capacity over the life of the vehicle.

The size of the canister needed for an integrated refueling/evaporative control system cannot be stated categorically since there are several other variables which must be considered such as purge rate, charcoal working capacity, and canister geometry. However, on average it is expected that a canister for an integrated refueling/evaporative system would be approximately 3 times as large as the one used for the present evaporative system.[17]

While the larger canister does not present any technical problems it may cause packaging problems on a few smaller vehicle models which could lead to canisters being placed in locations other than under the vehicle hood. While virtually all evaporative emission system canisters are now located under the vehicle hood there is nothing inherent in the design of an onboard system which requires that canisters for integrated systems also be located there. In fact, there may be some cost advantage to locating the canister near the fuel tank since the amount of larger vapor lines can be minimized. It is expected that manufacturers would place canisters in a location which provides the optimum mix of safety, cost, and performance characteristics.

(2) Refueling Vent Line Modifications

Also, in order to accommodate the higher vapor flow rates associated with refueling emissions, a larger vent line between the fuel tank and charcoal canister is needed along with a larger opening in the top of the fuel tank to accommodate the larger vent line. The current vent line to the canister associated with the evaporative system is about 3/8 inch. The vent line with the integrated evaporative/refueling system would be approximately 1/2 - 5/8 inch in diameter.[16] The larger vent line (and larger opening in the top of the fuel tank) introduce a few added complexities.

Unlike the limiting orifice used in evaporative emission systems, the larger opening required for an onboard system cannot provide liquid/vapor separation or rollover protection. Consequently, additional devices are required on an onboard system to meet these needs. The liquid/vapor separator, examples of which are shown in Figures 7 and 8, is simple in design and purpose.[14,18] It acts to remove gasoline droplets from the vapor stream and returns the liquid to the fuel tank to prevent liquid gasoline from entering the charcoal canister. Many design approaches are available in addition to those shown here. The separator itself may be a distinct component, or its function may be built into another component such as shown later in Figure 21. In terms of rollover protection, several simple devices are available which can prevent fuel spills during an accident, and also provide the benefits of a limiting orifice described above. These will be discussed in more detail in Section IV of this document since rollover and accident protection for the fuel system is primarily a safety issue.

Aside from the differences discussed above, onboard and evaporative emission control systems are very similar in design. They both act to direct, trap, and consume hydrocarbon vapor. Onboard systems require only a few additional components, and because they could be integrated into vehicle fuel systems to handle both refueling and evaporative

Figure 7

VAPOR-LIQUID SEPARATOR

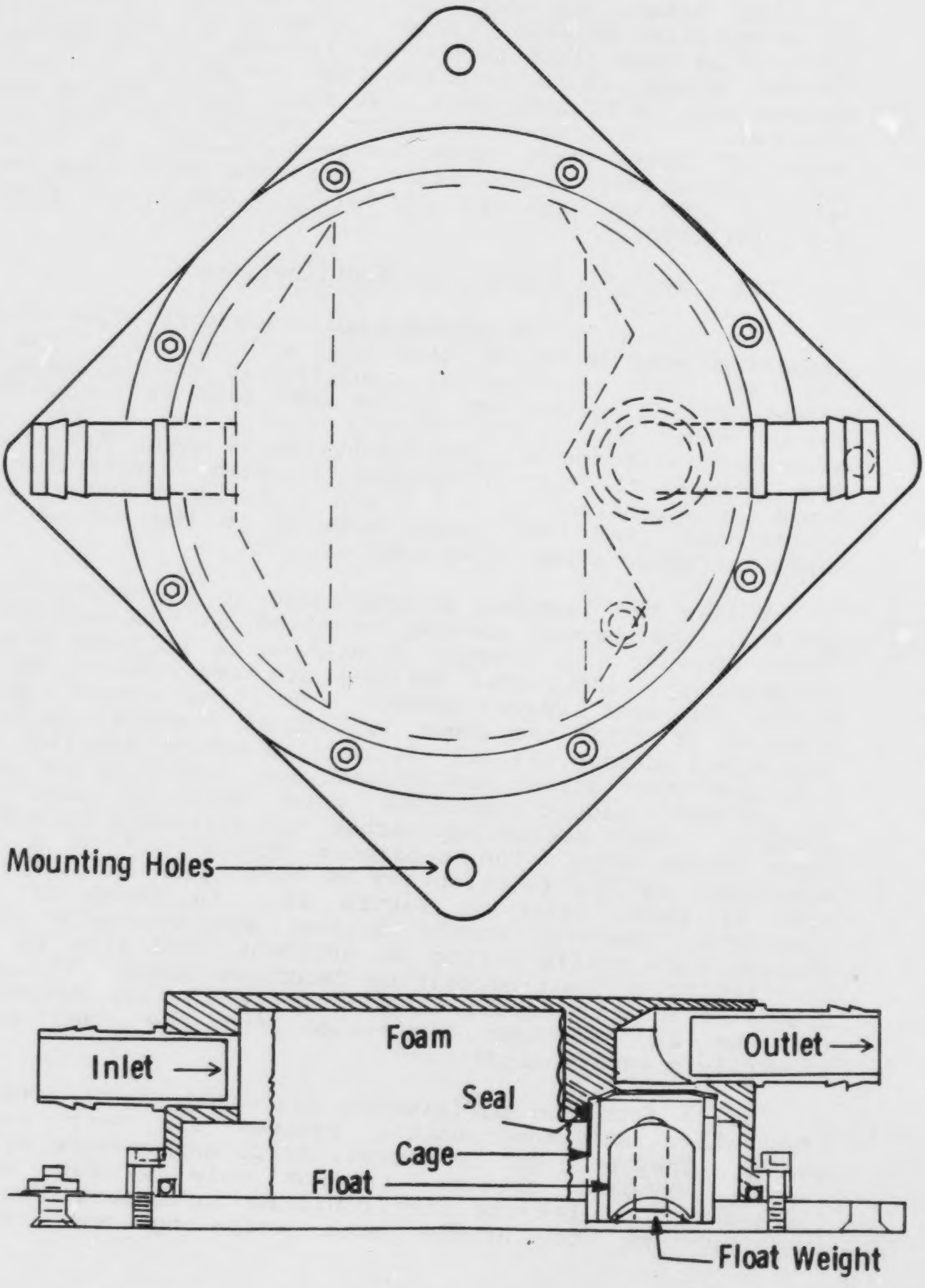
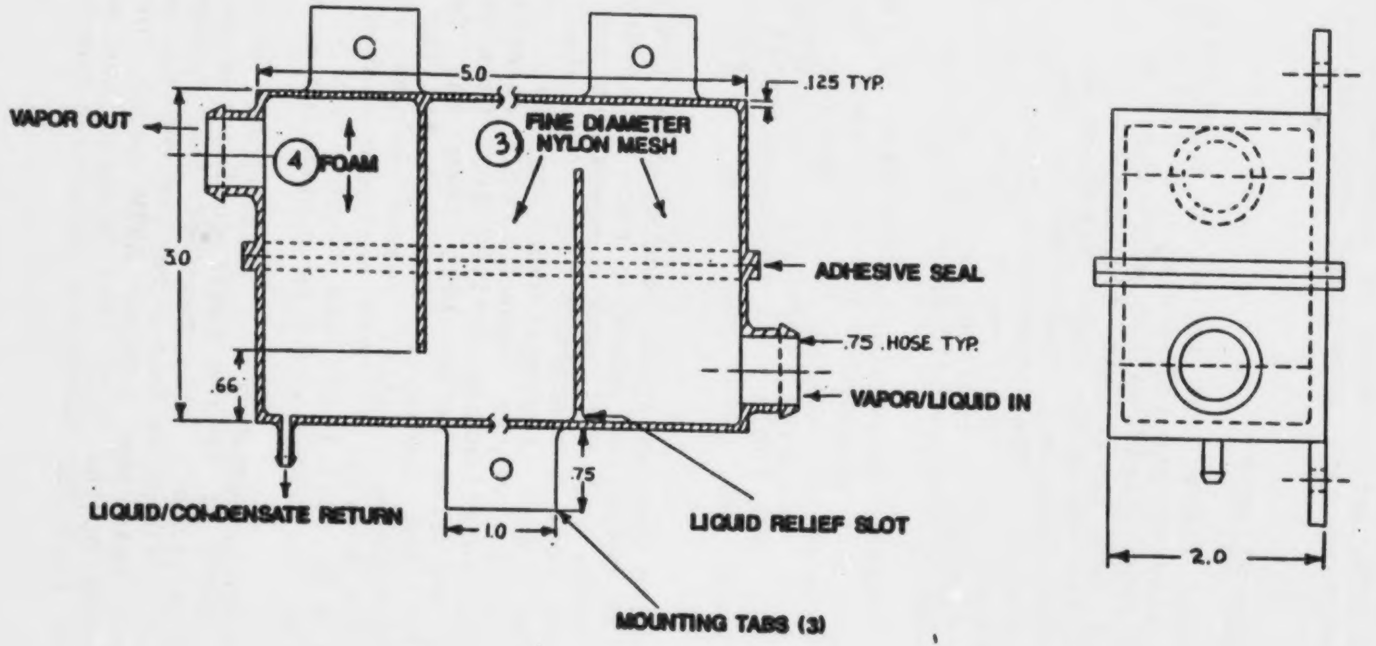

Mounting Holes
Foam
Inlet
Outlet
Seal
Cage
Float
Float Weight

Figure 8


5.0
.125 TYP.
VAPOR OUT
3
FINE DIAMETER NYLON MESH
4
FOAM
3.0
ADHESIVE SEAL
.75 .HOSE TYP.
.66
VAPOR/LIQUID IN
.75
LIQUID/CONDENSATE RETURN
1.0
LIQUID RELIEF SLOT
MOUNTING TABS (3)
2.0

4	AR	OPEN CELL FOAM		
3	AR	MESH FABRIC	NYLON	
2	1	UPPER HOUSING	PLASTIC	
1	1	LOWER HOUSING	PLASTIC	
ITEM NO	QTY REQD	DESCRIPTION	MATERIAL	SPECIF.
VAPOR - LIQUID SEPARATOR				
MUELLER ASSOCIATES, INC Baltimore, MD				
DATE 11/18/[illegible]	SCALE: FULL		PAGE 1 OF 1.	

emissions, overall control system complexity is not increased significantly. Also, because of the integration of the refueling/evaporative emission control functions, it should be apparent that many of the safety concerns associated with onboard systems have already been considered in designs of the present evaporative emission systems. The experience and knowledge gained in implementing safe evaporative emission systems provides a substantial base of information to use in designing and developing safe integrated evaporative/refueling systems.

3. Volatility Effects

As was mentioned above, the refueling emission rate is a key factor in the size of the onboard system canister, and the refueling emission rate itself varies with the fuel volatility and the dispensed and fuel tank temperatures. For design purposes, the canister would be sized based on the volatility and temperature specifications prescribed in EPA's refueling emissions test procedure. The parameters prescribed in EPA's procedure are based on near worst case summer season conditions, so the onboard canister would have capacity to achieve control under virtually all summer conditions.

However, as average temperatures decrease in the winter, RVP levels increase and dispensed and fuel tank temperatures decrease.[19] The question arises as to whether the onboard canister would have adequate capacity to capture winter emissions with higher RVP fuels. If the capacity is inadequate canister breakthrough may occur and some emissions may be uncontrolled.

Previous studies and analyses conducted by EPA and others have shown that the refueling emission rate increases with the fuel volatility (RVP) and fuel tank temperature and decreases with the dispensed fuel temperature.[19] One study (CAPE 9) used volatilities and temperatures typical of winter conditions.[20] Using winter season fuel volatilities and temperatures in the relationship derived from this study yields winter refueling emission rates less than the design load emission rate for the canister dictated by the refueling emissions test procedure. Winter season values (Dec - Feb) range from 5.1 to 5.9 g/gal for the northern states where RVPs are quite high (14-15 psi) while the design load value is 7.25 g/gal. Thus winter emissions would be controlled as well.

EPA is presently considering a program to control the volatility level (RVP) of in-use fuels during the summer months (mid-May to mid-September). As part of that program, in-use volatility levels nationwide would be limited to levels about 21.7 percent less than the current ASTM level for that area during the affected months. If that program was enacted, the volatility of the fuel for refueling emissions testing would be set at 9.0 psi RVP, the design load emission rate for the canister could drop to 6.0 g/gal, and onboard canisters could be somewhat smaller. However, as can be seen from comparison with the emission rate figures presented above, winter emissions would still be controlled.

While not the primary motivator, in-use volatility control may have some attendant safety benefits. Lower RVP fuels generate less vapor and thus could be considered somewhat safer in a general sense. More specifically, lower volatility fuels generate less fuel tank evaporative emissions and thus could reduce fuel tank pressurization problems which occur on some vehicles with damaged or altered evaporative emission systems (e.g. non-standard gas caps) operating under extremely atypical conditions. This pressurization could lead to some fuel/vapor being released from the fillpipe when the gas cap is removed, especially if the fuel tank was relatively full at the time. Lower vapor pressure fuel would reduce the degree of pressurization which could occur under these circumstances and thus reduce or eliminate the spillage which may result. Thus the safety of refueling operations would be improved.

IV. Design Considerations for a Safe System

As was discussed previously, several commenters have expressed concern regarding the potential safety implications of onboard systems. A review of these comments indicates that these concerns fall into two broad areas: the design of a safe onboard system and effects on in-use fuel system safety. Concerns in the first area will be addressed in this section. The section which follows (Section V) will address the later area of concern.

Comments received regarding the design of a safe onboard system fall in three categories: 1) safety test design requirements, 2) safety effects of maintenance, defects, tampering and repairs, and 3) refueling operation safety. EPA's summary and analysis of the comments in each category is presented below.

A. Safety Test Design Requirements

1. Introduction

Before analyzing the safety test design requirements it is interesting to look at fuel system safety from an in-use perspective for passenger cars meeting FMVSS 301. Presently, about 1.6 percent of all accidents involve a vehicle rollover of some type and about 0.5 percent of the rollover accidents result in a fire.[21] This results in a fire rate of 0.008 percent. Thus, neither rollover accidents or subsequent fires are common. Similarly, 0.14 percent of all front and rear end collisions lead to a vehicle fire.[21] Although vehicle crash fires are seemingly uncommon, approximately 1600 fatalities result each year from these fires.[22] Thus, from an in-use perspective, vehicle crash fires are unusual but serious events.

One of the most effective ways to protect against vehicle crash fires is to restrict fuel leakage during accidents by insuring the overall integrity of the vehicle's fuel system. To insure fuel system integrity during a crash, all currently manufactured passenger cars and light-duty truck's with a Gross Vehicle Weight Rating (GVWR) of 10,000 lbs or less, must comply with Federal Motor Vehicle Safety Standard (FMVSS) 301.[23] Basically, FMVSS 301 requires a vehicle to restrict fuel leakage to less than one ounce per minute when subjected to a rollover test following front and rear collisions at 30 miles per hour (mph), and side collision(s) at 20 mph. In a rollover test, a vehicle is turned on each of its sides and completely upside down and held in each of these three positions for a period of five minutes. Onboard system designs must take into account and protect against fuel leakage or other fire hazards which could occur in FMVSS 301 testing.

Along these lines, two issues exist regarding the design of an onboard system capable of passing FMVSS 301. These include rollover protection and the crashworthiness of key onboard system components and connections. As was discussed previously, onboard systems require the use of a somewhat larger vent line (about 1/2"-5/8" diameter as compared to 1/4"-3/8" on current vehicles) between the fuel tank and charcoal canister, and a similar sized orifice would exist in the fuel tank. While the external vent line used on many current fuel tanks also requires a 1/2" orifice, manufacturers' onboard system designs may incorporate a rollover protection device to protect against fuel leakage during an FMVSS 301 rollover test even though present designs do not. Also, vehicle crashes present the possibility of direct or indirect damage to fuel system components. In some cases this damage could lead to a fuel leak or increase the potential for a vehicle fire in some other portion of the fuel system. Thus a properly designed onboard system must not compromise the crashworthiness of the system and key components.

2. Rollover Protection

A rollover protection device is basically a valve that would close off the refueling vent line whenever the risk of fuel leakage existed. Several rollover protection designs have been proposed by auto manufacturers and other interests which could adequately perform this safety function. Several of these are discussed below.

One design which has been proposed by several sources can be termed the nozzle actuated valve. The valve is integral to the fillpipe and is located near the top of the fillpipe, perhaps near the leaded fuel restrictor. During refueling, the valve is opened by the insertion of a fuel nozzle. With the valve open, a clear passage through the vent line is available to allow for the routing of refueling vapors to the charcoal canister. Other than during refueling, the valve remains closed and effectively eliminates the potential for fuel leakage through the refueling vent line during a rollover accident. Figures 9 thorough 15 show five different nozzle actuated valve assemblies capable of performing the rollover protection function.[13,15,18,24] Figures 9 through 13 also demonstrate how nozzle insertion would open the valve to provide a large orifice for the venting of fuel tank vapors during refueling and when the nozzle is removed the vent line would be closed.

Also, while a rollover protection device might be necessary, it is interesting to note that many current production passenger car and light truck models (mostly side fill) employ an external vapor vent line of about 1/2" diameter that connects the fuel tank to the top of the fillpipe (see Figure 1). This external vent line is approaching the size needed for a refueling vent line, and yet manufacturers have included these external vent lines without any rollover protection device. As will be discussed below, depending on the design used, a rollover protection system may actually enhance safety over current designs.

This analysis has presented several basic rollover valve designs capable of providing the protection required by FMVSS 301 tests. Manufacturers could choose to implement one of these approaches, or could develop another. The approach ultimately selected will be that which provides cost efficient protection, is compatible with the other components of the manufacturers onboard system, and can be integrated effectively into the vehicle design from both safety and operational perspectives.

3. Component/System Crashworthiness

The second issue regarding safety test design requirements involves the crashworthiness of the key components of an onboard system. This includes those components most susceptible to damage in an accident (nozzle actuated rollover valve, charcoal canister) and the structural integrity of the vapor line (and connections) which may exist between the top of the fuel tank and the rollover valve. A problem in one of these three areas could cause a vehicle to fail FMVSS 301 tests and must be addressed in proper system design. Each of these concerns is discussed below.

Figure 9

SEALED FILLER NECK SYSTEM
TANK VENT VALVE ASSEMBLY
(DURING NORMAL VEHICLE OPERATION)

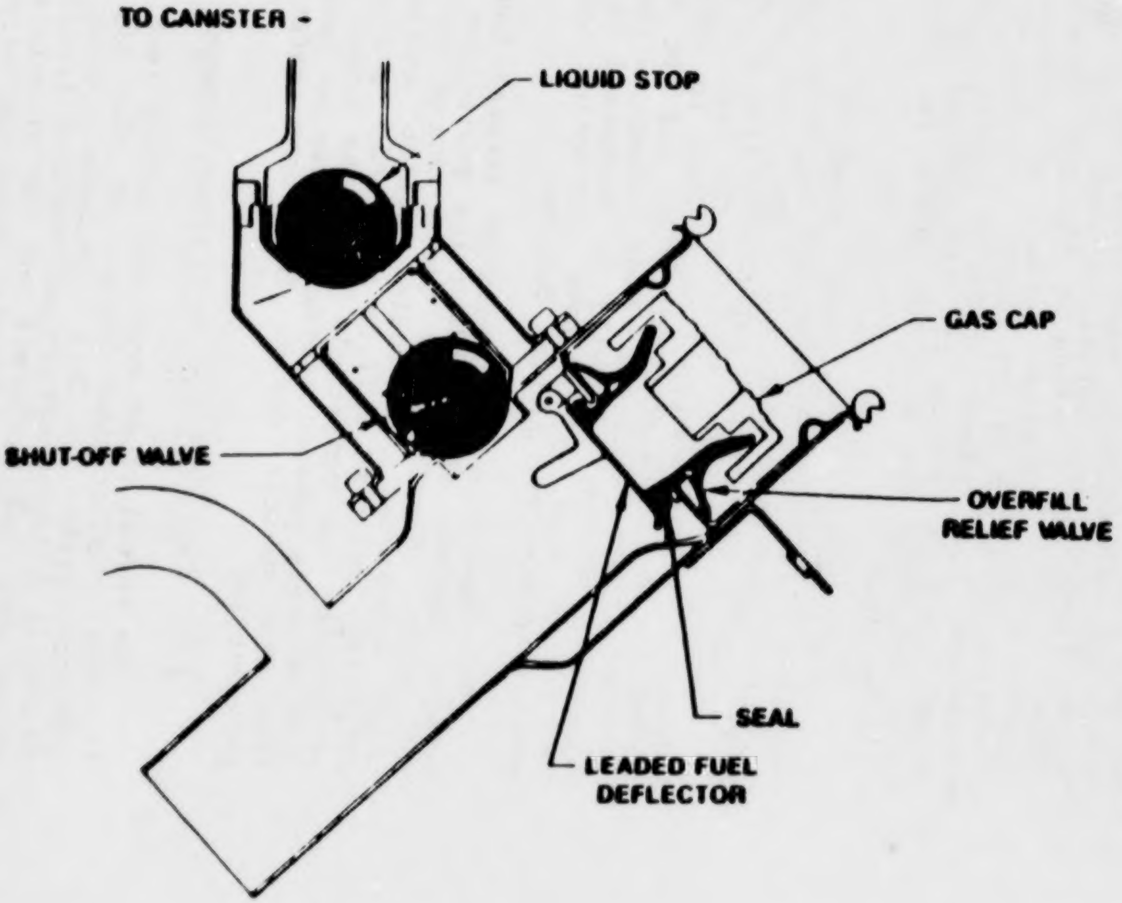

TO CANISTER -
LIQUID STOP
GAS CAP
SHUT-OFF VALVE
OVERFILL RELIEF VALVE
SEAL
LEADED FUEL DEFLECTOR

Figure 10

SEALED FILLER NECK SYSTEM TANK VENT VALVE ASSEMBLY
(DURING REFUELING EVENT)

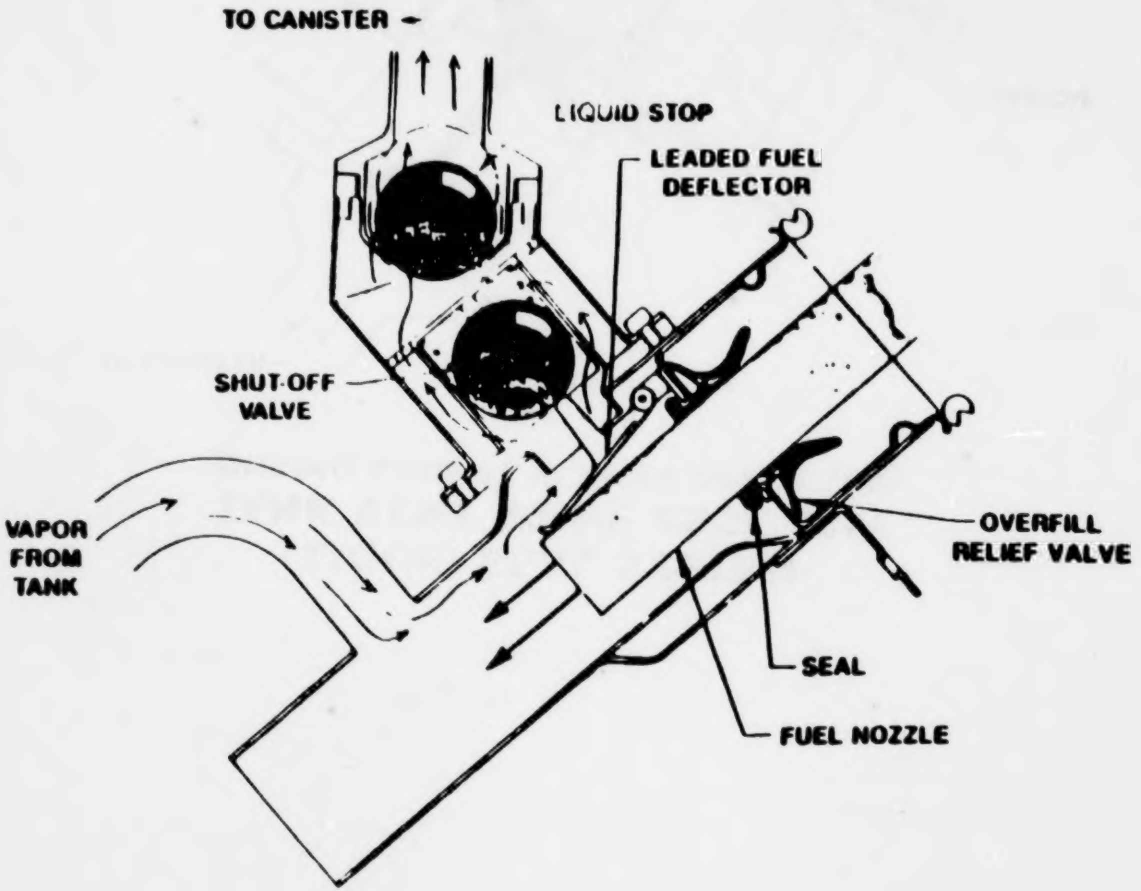

TO CANISTER
LIQUID STOP
LEADED FUEL DEFLECTOR
SHUT-OFF VALVE
VAPOR FROM TANK
OVERFILL RELIEF VALVE
SEAL
FUEL NOZZLE

Figure 11

LIQUID SEAL SYSTEM
TANK VENT VALVE ASSEMBLY
(DURING NORMAL VEHICLE OPERATION)

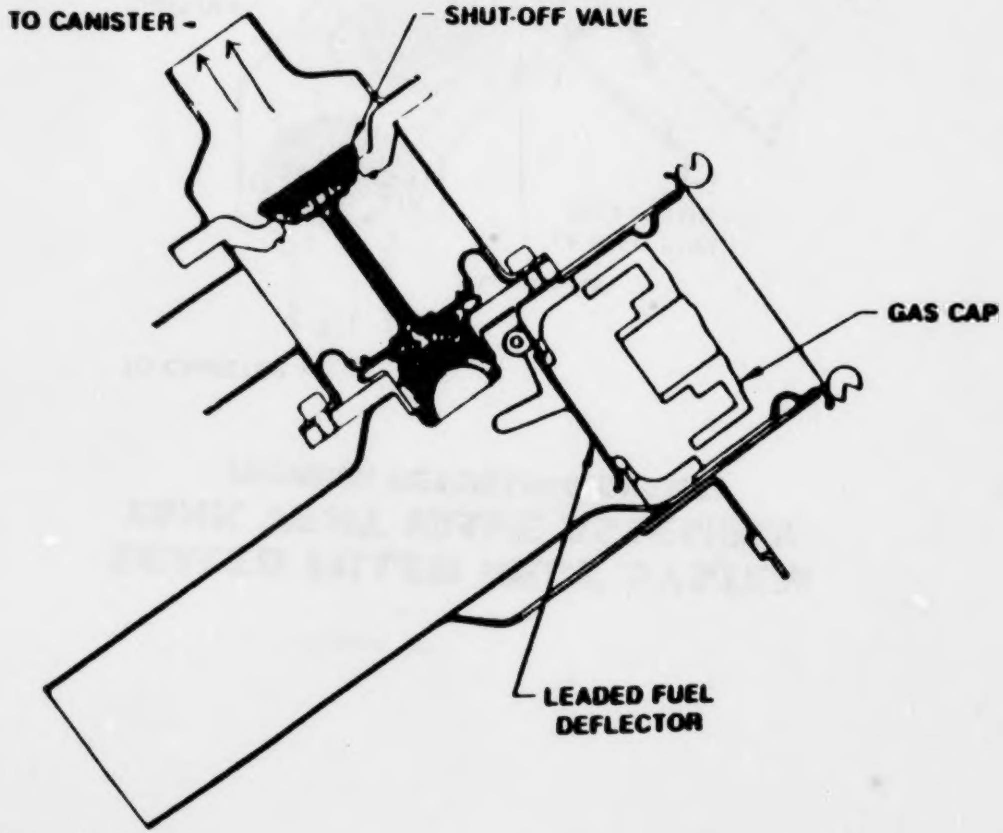

TO CANISTER
SHUT-OFF VALVE
GAS CAP
LEADED FUEL DEFLECTOR

Figure 12

LIQUID SEAL SYSTEM
TANK VENT VALVE ASSEMBLY
(DURING REFUELING EVENT)

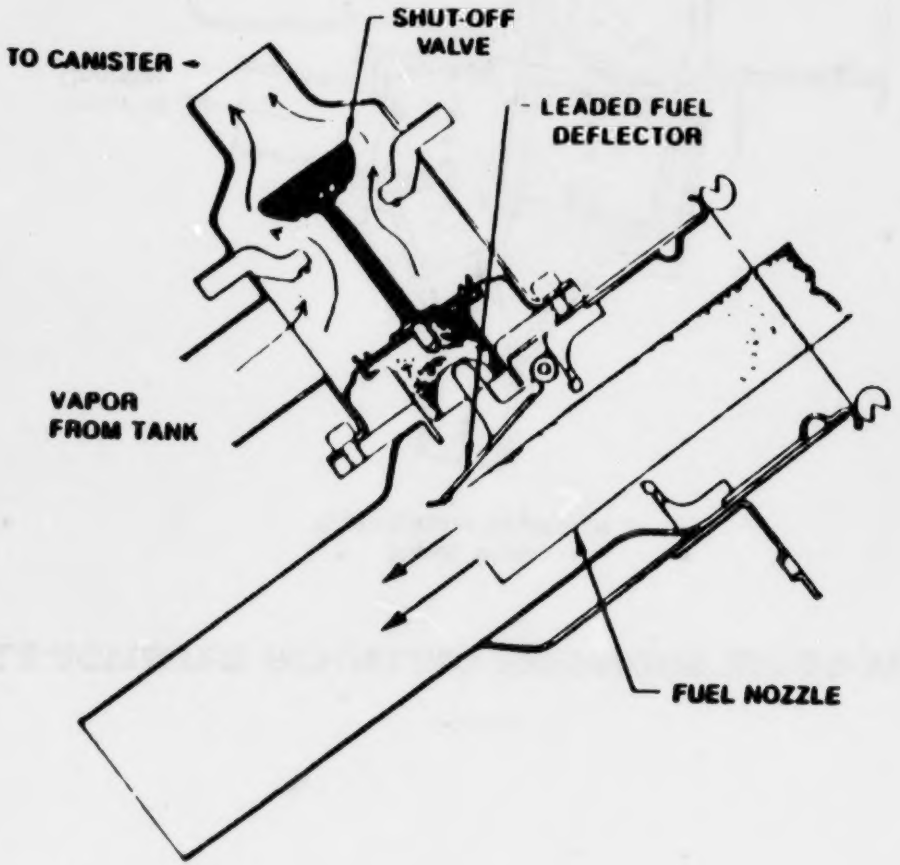

SHUT-OFF VALVE
TO CANISTER →
LEADED FUEL DEFLECTOR
VAPOR FROM TANK
FUEL NOZZLE

Figure 13

NOZZLE-ACTUATED REFUELING EMISSIONS VAPOR VENT VALVE

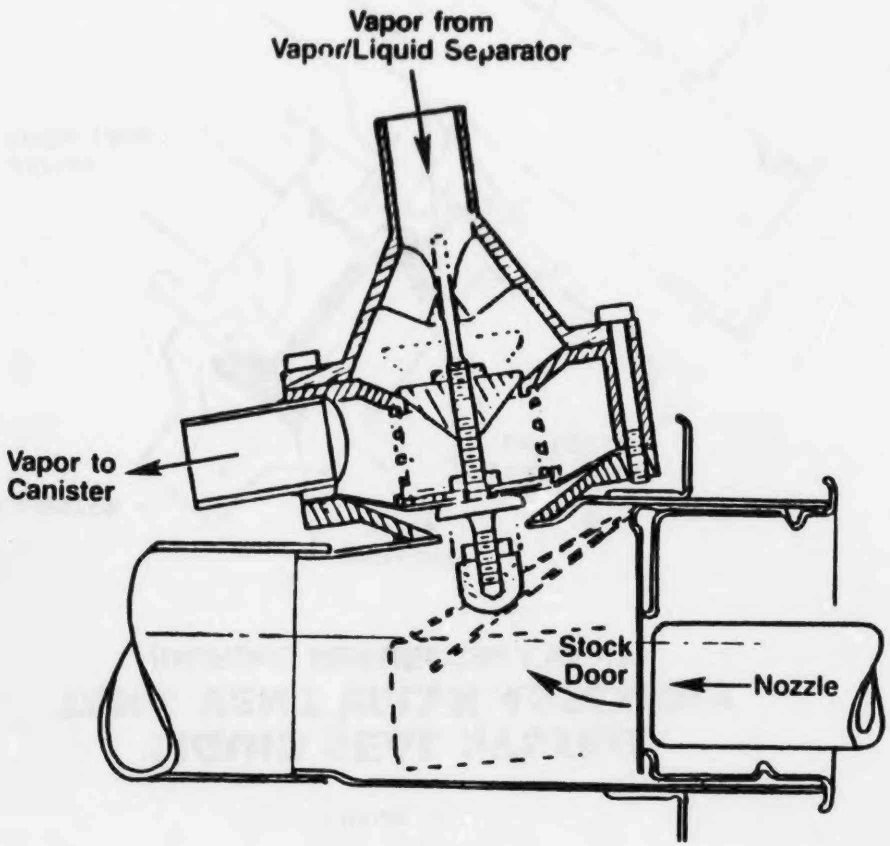
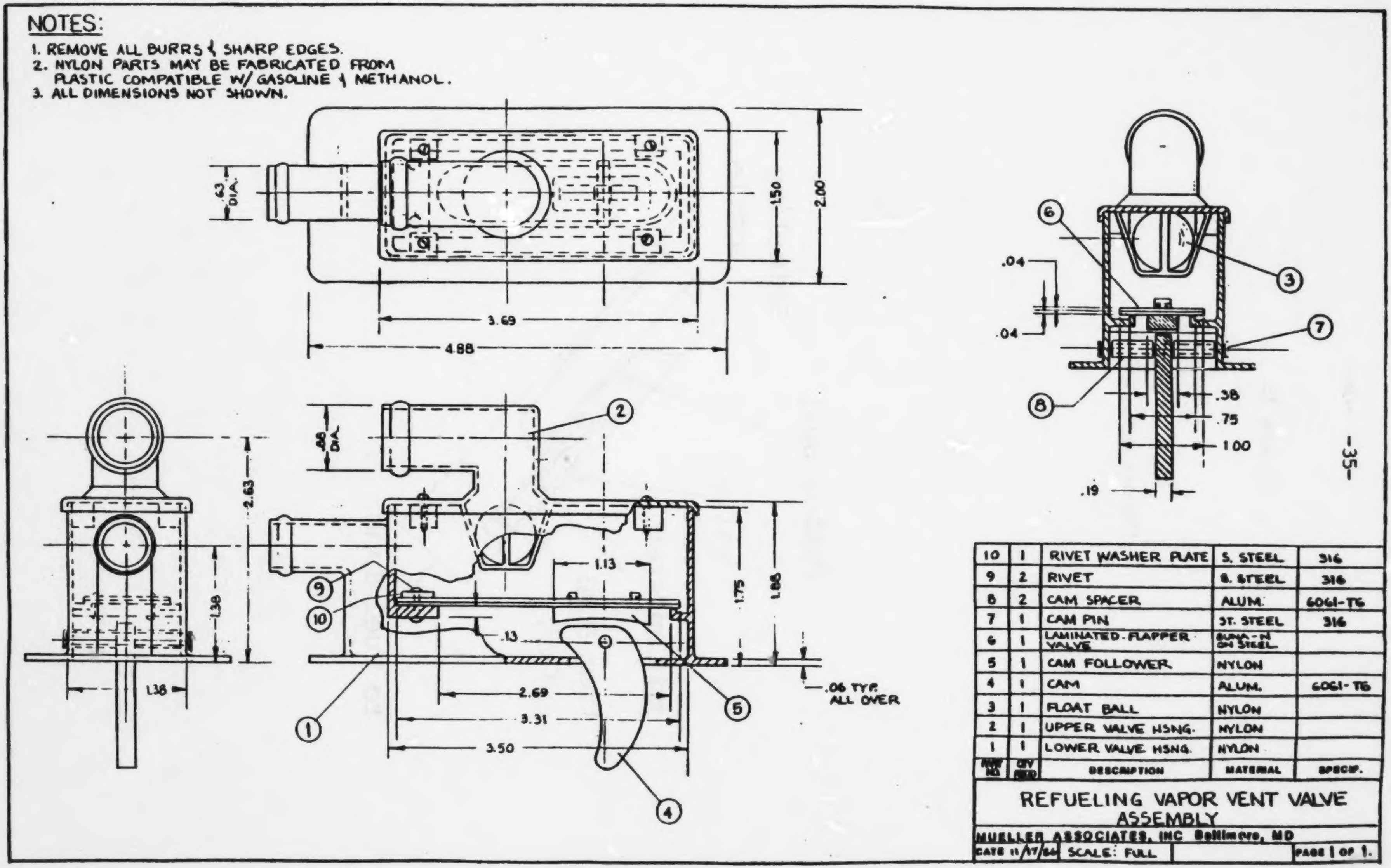

Vapor from
Vapor/Liquid Separator
Vapor to
Canister
Stock
Door
Nozzle

Figure 14


.63 DIA.
1.50
2.00
3.69
4.88
2.63
1.38
1.38
.88 DIA.
1.13
1.75
1.88
.13
.06 TYP. ALL OVER
2.69
3.31
3.50
.04
.04
.38
.75
1.00
.19
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩

NOTES:

1. REMOVE ALL BURRS & SHARP EDGES.
2. NYLON PARTS MAY BE FABRICATED FROM PLASTIC COMPATIBLE W/ GASOLINE & METHANOL.
3. ALL DIMENSIONS NOT SHOWN.

ITEM NO.	QTY REQD	DESCRIPTION	MATERIAL	SPECIF.
10	1	RIVET WASHER PLATE	S. STEEL	316
9	2	RIVET	S. STEEL	316
8	2	CAM SPACER	ALUM.	6061-T6
7	1	CAM PIN	ST. STEEL	316
6	1	LAMINATED FLAPPER VALVE	BUNA-N ON STEEL	
5	1	CAM FOLLOWER	NYLON	
4	1	CAM	ALUM.	6061-T6
3	1	FLOAT BALL	NYLON	
2	1	UPPER VALVE HSNG.	NYLON	
1	1	LOWER VALVE HSNG.	NYLON	

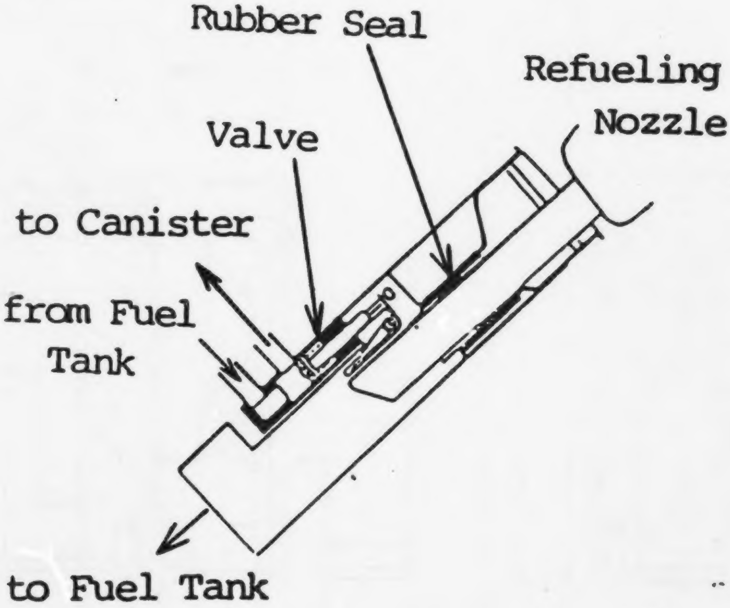
REFUELING VAPOR VENT VALVE
ASSEMBLY

MUELLER ASSOCIATES, INC Baltimore, MD

DATE 11/17/84 SCALE: FULL PAGE 1 OF 1.

Figure 15

"Toyota Concept"


Rubber Seal
Refueling Nozzle
Valve
to Canister
from Fuel Tank
to Fuel Tank

However, before beginning these discussions, it should be noted that component/system crashworthiness is not at all a new concern. Manufacturers must address these same concerns in the design of the current evaporative emission systems. Given the similarity of onboard refueling and evaporative controls, and that many systems will be integrated, there should be no new or unique problems in this area.

a. Rollover Valve

First, the crashworthiness of the rollover protection device is a design consideration for nozzle actuated valves, since they would be located near the exterior shell of the vehicle. Integration of nozzle actuated valves into the overall vehicle design would have to include a consideration of the potential to sustain damage if struck in a collision.

However, this design consideration is straightforward, and it is reasonable to expect that manufacturers can and will integrate rollover valves into their fillpipe designs without decreasing the structural integrity of the fillpipe while providing crashworthiness for the valve. For example, it is worth noting that vehicle manufacturers have dealt with similar problems in their designs of fillpipes, external vapor vent lines, and gas caps, and in fact, one would not expect the nozzle actuated rollover valve to be any more susceptible to damage than these components. As was mentioned previously, the 1/2" external vent line lies in this same area on the vehicle, and yet manufacturers have included such vent lines without a rollover protection device.

b. Vapor Line

Similarly, manufacturers will have to be cognizant of the structural integrity of the vapor line and vapor line connections, if any, between the fuel tank and the rollover valve. These would have to be designed to withstand the stresses which might occur in a crash in order to maintain fuel system integrity. However, there is no significant engineering challenge to accomplishing this objective.

The integrity of this portion of the vehicle's vapor line can be assured through use of a vapor line material of proper strength, flexibility, and durability. A number of vapor lines of different material, wall thickness, and construction are currently available. In addition, routing of this portion of vapor line is another design parameter available to manufacturers. As a matter of course, manufacturers are expected to insure that the line is protected from abrasion and normal wear and that it is not in a vulnerable location in the event of a collision. This is considered straightforward given that on integrated systems the refueling vapor line now replaces that used for control of diurnal evaporative emissions. Similar routings would be expected. Vapor line integrity and connections in current vehicles must meet similar requirements, and it is reasonable to expect that similar materials and connecting approaches would be used.

Finally with regard to vapor line integrity and connections, it is worth noting that many vehicle models now use a flexible insert between the fillpipe and fuel tank to enhance the fuel system safety in-use (see Figure 16).[15] Similarly, in many vehicle models the external vent line actually incorporates a flexible vapor line which connects the metal portions of the external vent line from the top of the fuel fillpipe and the fuel tank (see Figure 16). These connections are subject to the same performance requirements as would be needed for onboard system vapor lines and in some cases are even more critical and demanding. Evidence is that these have been incorporated safely. The manufacturers' experience with current vehicle evaporative and fuel systems described above demonstrates that vapor line and vapor line connections can be made to withstand the stresses which occur in a vehicle accident.

c. Charcoal Canister

Concerns regarding the crashworthiness of the charcoal canister center on the possibility that a canister ruptured in an accident could present a fire hazard if an ignition source exists nearby.

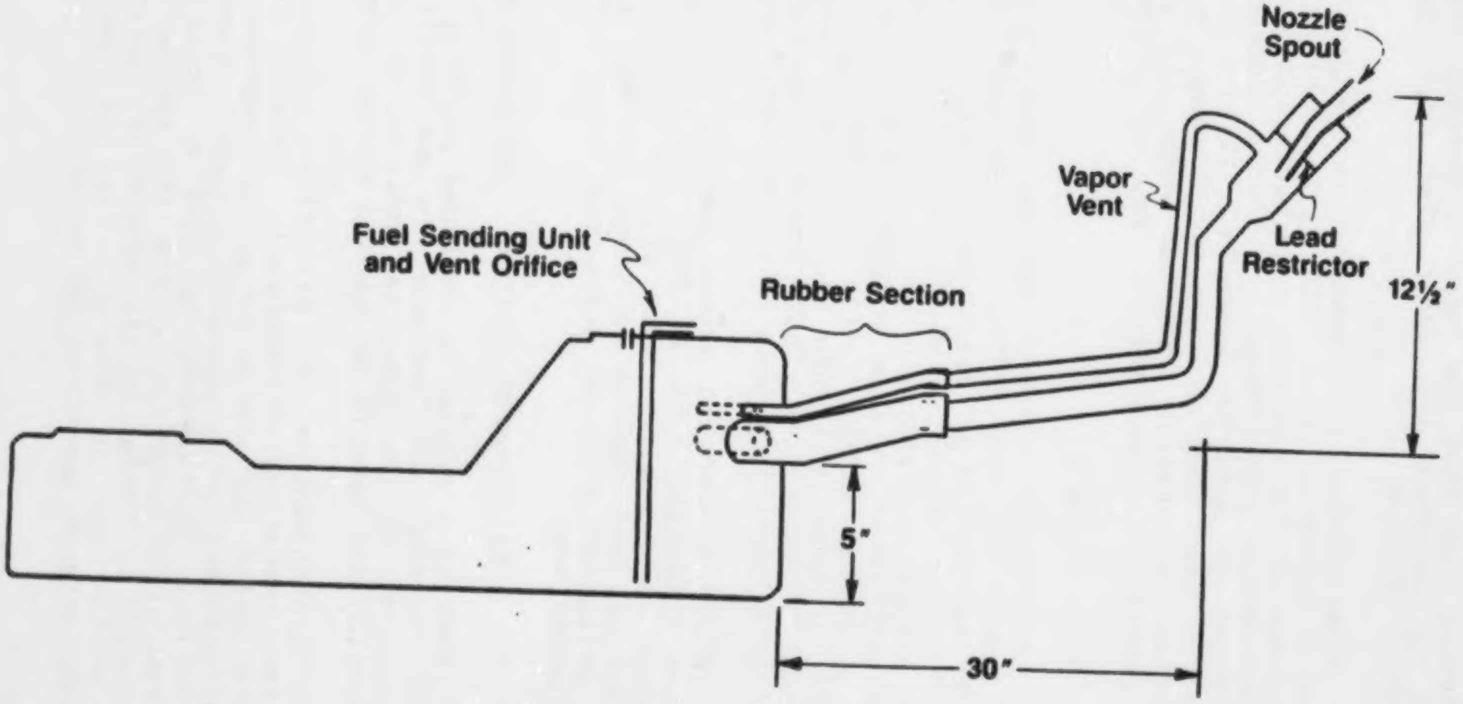
Even if the rupture of the integrated refueling/evaporative canister occurred in some cases, the potential hazard should not be overstated. While carbon canisters do contain gasoline vapor, they are strongly adsorbed to active sites within the carbon bed and not easily released to the atmosphere. Thus, even if a canister were crushed and its contents dumped, gasoline vapor would not be present in the atmosphere in sufficient quantity to be flammable. There is no available evidence of "canister fires" in any accidents involving vehicles with evaporative systems. The fact that onboard canisters would be larger and would hold more vapors initially than current evaporative systems makes no difference. While the refueling load to the canister is larger than the evaporative load, after the first few miles of driving the canister would be purged such that the amount of vapor remaining in the canister is essentially the same as that present in current evaporative emission canisters alone.* The

---

* Due to the nature of the charcoal used to trap hydrocarbon vapors, and strict certification test requirements, hydrocarbons would be quickly stripped from the charcoal early in the purge process. Therefore, during most of the operation of the vehicle (90 percent), the charcoal canister does not contain enough hydrocarbon vapor to present any safety risks.[9]

Figure 16

BUICK CENTURY FUEL TANK AND FILLPIPE PRODUCTION CONFIGURATION


Nozzle Spout
Vapor Vent
Lead Restrictor
Fuel Sending Unit and Vent Orifice
Rubber Section
12½"
5"
30"

lack of risk from charcoal canisters is supported by a recent submission from Nissan to EPA, stating that no safety problems would be expected with refueling canisters.[25] Thus it could be argued that the hazard, if any, is not significantly different than that now found on present systems. Thus, it is hard to perceive any added risk from the use of a larger charcoal canister.

Nevertheless, if a manufacturer believed that the canister posed a potential risk, the risk could be eliminated through placement of the canister in a protected area such as the rear of the engine compartment or in some underbody area as has been suggested by some manufacturers.[12,13] In most cases it is expected that manufacturers would simply place the integrated refueling/evaporative canister where the present canister is now located; in these cases no new design issues really exist.

d. Summary

In summary, current fuel and evaporative emission systems must meet the same FMVSS 301 requirements and much of the experience gained in designing and building current systems can be directly extrapolated to implementing an onboard system. The analysis presented above leads to the conclusion that straightforward, viable engineering solutions exist to address any potential safety design concerns, and that onboard systems can be incorporated into the vehicle's fuel/evaporative system without compromising fuel system integrity or reducing the vehicle's ability to pass FMVSS 301 requirements.

While an onboard system can be designed to provide fuel system integrity both in FMVSS 301 testing and in-use, it is prudent to consider the effects of maintenance, defects, tampering, and repairs on these systems, and means to address any potential problems which may exist. These issues will be addressed next.

B. Maintenance, Defects, Tampering and Repairs

Even if a system is designed properly and functions safely under "normal" and "extreme" in-use conditions, some question remains as to the potential effects of maintenance, defects, tampering and repairs on onboard system safety.

Maintenance is the prescribed actions needed to keep a system operating as designed. Defects involve the improper operation of the system or system components caused by design, manufacturing, or assembly errors. Tampering involves the intentional disablement (partial or total) or removal of the system or a component within the system, and repairs involve restoring or replacing the system or system components because of malfunction or damage. Each of these events and their safety effects are discussed below.

1. Maintenance

First, an onboard system is expected to be essentially maintenance free (no scheduled maintenance) as are current evaporative control systems. EPA's emission factor testing has found that non-tampered fuel-injected vehicles generally comply with the evaporative emission standards without maintenance. Furthermore, EPA's requirements for light-duty truck and heavy-duty gasoline vehicle emissions certification do not allow evaporative system maintenance up to 100,000 miles, and a similar requirement is being considered for an onboard system. The technology used here can be used for passenger cars as well. Thus, maintenance will not be necessary for proper functioning of an onboard system over the life of a vehicle. Therefore, lack of prescribed maintenance will not lead to safety problems.

2. Defects

Second, with regard to defects, the primary safety related concern deals with the possibility that defects in the operation of one or more components of the onboard system in-use might lead to safety problems for the vehicle. This includes possible problems with components such as the liquid/vapor separator, purge valve, charcoal canister and rollover valve.

Since onboard system components such as the liquid/vapor separator, purge valve, and charcoal canister are very similar to those used in evaporative systems, one method to assess the potential safety effects of defects is to review the experience seen with evaporative systems. In an effort to quantify the potential for defect problems regarding onboard systems, three different computer files provided by NHTSA were reviewed for evidence as to defects pertaining to the evaporative emission system which could impact vehicle safety in-use.[26] The files reviewed covered recalls, service bulletin reports, and owner complaints current as of November, 1986 for all three vehicle classes (passenger car, light truck, and heavy-duty gasoline). A review of the recall files revealed only 12 cases that could be even remotely linked to the evaporative emission system out of an estimated 3,000 families which have been certified with evaporative emission systems. Service bulletin reports for dealers added an additional 21 cases for a total of 33 possible problems out of over 3,000 families. None of these were identified as having caused an accident; the vast majority were more emission system performance than safety defects. Finally, a review of the owner complaints indicated only about 100 problems out of over 180 million vehicles sold with evaporative emission controls. In only a few of the owner complaints did safety problems actually occur, and no significant damage was reported. On a percentage basis these potential problems are very small.

Two other valuable observations can be drawn from a review of these files. Problems/complaints have diminished with newer model year vehicles with evaporative controls, which demonstrates that gaining experience leads to product improvement. Given the similarity between onboard refueling and evaporative emission controls, and the fact that the two systems will be integrated in most cases, much of this experience will be directly transferable to onboard systems and thus improve in-use performance. Second, the review of the owner complaints files indicated no trends other than those related to improvements in newer model year vehicles; thus no systematic problems in components or systems were evident.

Further, it is important to note that the very mechanisms used to generate the files for this survey would actually act to help eliminate any potential in-use safety effects of onboard systems defects. Dealer service bulletin reports are effective in dealing with problems raised at the dealerships, and owner complaints assist the manufacturers and NHTSA in assessing the need to conduct voluntary or mandatory recalls. Finally, to place the potential for defect problems from onboard systems in context, it should be noted that the onboard risk is essentially incremental to that now seen for evaporative systems, since in most cases the refueling and evaporative systems would be integrated. On an incremental basis, the frequency of defects would likely be unaffected.

Finally, since a rollover valve could be used on some onboard system designs specifically to enhance safety and they are not used on current vehicles, it is worth discussing the possibility of valve defects. First, it should be noted that defects in these valves should be rare. Manufacturing engineering techniques permit the development and production of highly reliable valves and statistical quality control techniques are available to insure that production valves meet design standards. In fact, if a rollover valve is defective at the vehicle assembly point, the vehicle will probably not be able to accept the fuel provided at the end of the assembly line, and repairs will be needed even before the vehicle leaves the plant. Second, to insure in-use protection, rollover valves must be designed to fail in the closed position. This would be considered "safe" because a closed position valve failure would never cease providing rollover protection and it would effectively block the refueling vent line and make refueling the vehicle extremely difficult. This difficulty would provide incentive for the vehicle operator to identify and repair the failure. If the valve failed during operation of the vehicle, the fuel tank would vent any vapors through the limiting orifice or gas cap to prevent any pressure build up (See Figures 3 and 4). Also, rollover valve failure might be one component of an onboard system which could be incorporated into onboard vehicle diagnostics and thus allow the operator notice of the problem when it occurs and provide an opportunity for repair before the fuel level becomes critical. Fail safe designs would be effective in achieving both protection and repair, and that the other measures discussed above would assist in eliminating or addressing any in-use defects.

3. Tampering

A third area of potential safety problems involves the effects of possible system tampering. While several types of tampering occur with evaporative emission systems (see Table 1), past in-use experience with these systems shows that only one type, disconnection and/or removal of the charcoal canister, might be a safety problem for onboard systems. This type of tampering poses a possible safety hazard because during the refueling operation it would lead to a flow of gasoline vapor into the atmosphere at the point where the missing canister had been located. While the gasoline vapor mixture reaching the canister location in this situation would be well above the upper flammability limit, it would briefly be flammable as the vapor dissipates and at the air/vapor transition zones. If a spark or other ignition source were present, the mixture could briefly burn. While this situation is likely to be rare, the possible safety effects of such an occurrence must be considered in the onboard system design.

There are several points which need to be made relative to canister tampering. First, this is not unique to onboard systems - similar potential problems now exist with evaporative emission canisters but a safety concern regarding tampering with evaporative emission system canisters has not surfaced. Second, using current evaporative emission canisters as an indicator, this situation is likely to be rare for integrated onboard refueling/evaporative canisters. As is shown in Table 2, current average canister tampering is only about 3 percent of all vehicles, and similar rate would be expected for integrated refueling/evaporative emissions canisters. Third, if the canister were located in an area which would be difficult to access, tampering could be further discouraged.

Further, the potential problem could be reduced through proper placement of the canister in a location distant from any ignition sources. Possible locations include the rear of the engine compartment (as is done with some evaporative canisters) or in some underbody area as has been suggested by some manufacturers for packaging reasons. Placing the canister in an underbody area would also reduce the potential for tampering by making it less accessible to the owner as mentioned above. While canister tampering is infrequent, and means exist to discourage such actions even further, good engineering judgment dictates that canisters not be placed in a location where tampering could create a safety hazard. It is expected that manufacturers will take all reasonable steps necessary to reduce tampering, and that refueling canisters would not be placed in locations where their removal could create a safety risk.

Table 1

Types of Tampering Problems And Typical Rates of Occurrence

Problem	Rate of Occurrence (%)
Gas Cap Removed	1.2%
Canister Vacuum Disconnected	1.7
Cap Removed & Canister Vacuum Disconnected	0.1
Canister Removed	0.3
Non-vacuum Canister Disconnection	0.2
Total Disablements	3.5%

---

* Tampering rates calculated from the combined data from the EPA Tampering surveys performed in 1982, 1983 and 1984 (9,142 vehicles).

Table 2

Canister Tampering Survey Results By Year*

Passenger Car and Light Truck**

Year	% Tampered
1978	3
1979	2
1980	No Report
1981	2
1982	2
1983	5
1984	3
1985	4
Avg	3

---

* Motor Vehicle Tampering Survey - 1985, US EPA, OAR, OMS, FOSD, November 1986.

** Since HDGVs did not require evaporative controls until 1985, survey data is currently not available for these vehicles.

4. Repairs

Finally, repairs of onboard systems may have some safety implications. Since an onboard system is essentially maintenance free, any damage to the system (besides that from defects or tampering) would in most cases result from a vehicle accident. An accident which damages the vehicle's fuel system would be relatively severe and require critical vehicle repairs. Such vehicle repairs, in general, would demand a professional certified mechanic in a licensed facility. These mechanics should be properly trained and have access to current shop manuals to repair and package the fuel system and onboard components correctly to ensure effective and safe performance. They also should be aware of any potential safety hazards of improper installation or omission of onboard system components. Furthermore, these mechanics would normally have no economic incentive for improperly repairing an onboard system or omitting some components since the facility would be compensated for all of the parts and time spent repairing the vehicle.

In any repairs of the fuel system with an onboard control system, there is only one critical area with respect to safety. This critical area is the connecting line between the top of the fuel tank and the rollover valve at the top of the fillpipe. An improper installation or connection in this area could result with fuel leakage in the event of a vehicle rollover. This connection, however, is not unique to fuel tanks with onboard systems. It is very similar to the external vapor vent line that appears on many of today's vehicles, and thus incrementally the situation may be no different than on today's vehicles. Thus, repairs of onboard systems should not create any potential safety hazards as compared to present day fuel systems.

5. Summary

In summary, component maintenance, defects, tampering, or repairs should not create the potential for in-use safety risks. An onboard system is expected not to require any scheduled maintenance. Thus, any lack of maintenance by the vehicle owner should not introduce safety hazards.

There is no evidence to indicate that possible defects in other onboard system components would lead to safety problems. There are very few defects with present evaporative emission systems, and since it is likely that refueling and evaporative emission systems would be integrated, the overall defect rate is likely to be no different than that seen in present vehicles. Further, methods are available to assure that reliable rollover valves are installed in vehicles and to insure rollover protection in the unlikely event of a valve failure.

While canister tampering effects must be considered, it should be noted that it presently is uncommon, and this low rate is expected to continue for onboard systems. Also, tampering could actually decrease through judicious canister placement on the vehicle. Nevertheless, prudent design practices dictate that manufacturers not place canisters in a location where tampering could lead to a safety problem, and it is expected that this approach would be followed.

Any repairs of an onboard system, besides those resulting from defects or tampering, will probably occur as a consequence of accident damage to the vehicle. Since the damage will most likely be severe, it will require the use of a certified mechanic who is properly trained for such repairs. Further, the only critical area of the onboard system which could impose any safety hazard if improperly repaired are the components and connections between the fuel tank and fillpipe top. Repairs are also critical in this area for current vehicles using external vapor vent lines, so there may be no change in risk over present vehicles. Repairs to an onboard system should not inherently increase the potential for in-use safety risks.

An onboard system design must also include consideration of potential effects on the safety of refueling operations. This is discussed in the next section.

C. Refueling Operation Safety

1. Fuel Tank Overpressure During Refueling

The first potential safety issue involves the possibility of pressure build-up in the fuel tank during the refueling of a vehicle equipped with an onboard system. Whenever a system is designed to be "sealed" from its environment, some forethought must be exercised to evaluate the possibility and consequences of an overpressure within the system.

Although an onboard system does not completely seal off a vehicle's fuel tank, it is designed to allow for only one opening, the refueling vapor vent line. If for some unusual reason, the vent line were to become fully or partially blocked or the nozzle automatic shut-off mechanism failed during a full refill, excess pressure could build in the fuel tank. This concern is only associated with an onboard system utilizing a mechanical seal as illustrated in Figure 3. With a liquid seal system (see Figure 4), excess pressure cannot build up in the tank during refueling because fuel would simply flow out the fillneck opening (the same way it currently does) and the nozzle operator could then stop the fuel flow. Liquid seal systems would function in the same manner as current fuel systems. From the nozzle operator's viewpoint, the refueling operation remains the same.

If a manufacturer elects the mechanical seal design, he must incorporate a simple pressure relief device capable of relieving fuel tank pressure. In the event of a nozzle failure or vent line blockage, this device would eliminate potential tank overpressurization by opening an "emergency" passage to the atmosphere through which pressurized vapor and any gasoline would spill onto the pavement or some other location noticeable to the nozzle operator. This spillage would make the fuel pump operator aware of the problem and fuel flow could be stopped without causing damage to the fuel system or causing fuel to spitback on to the operator.

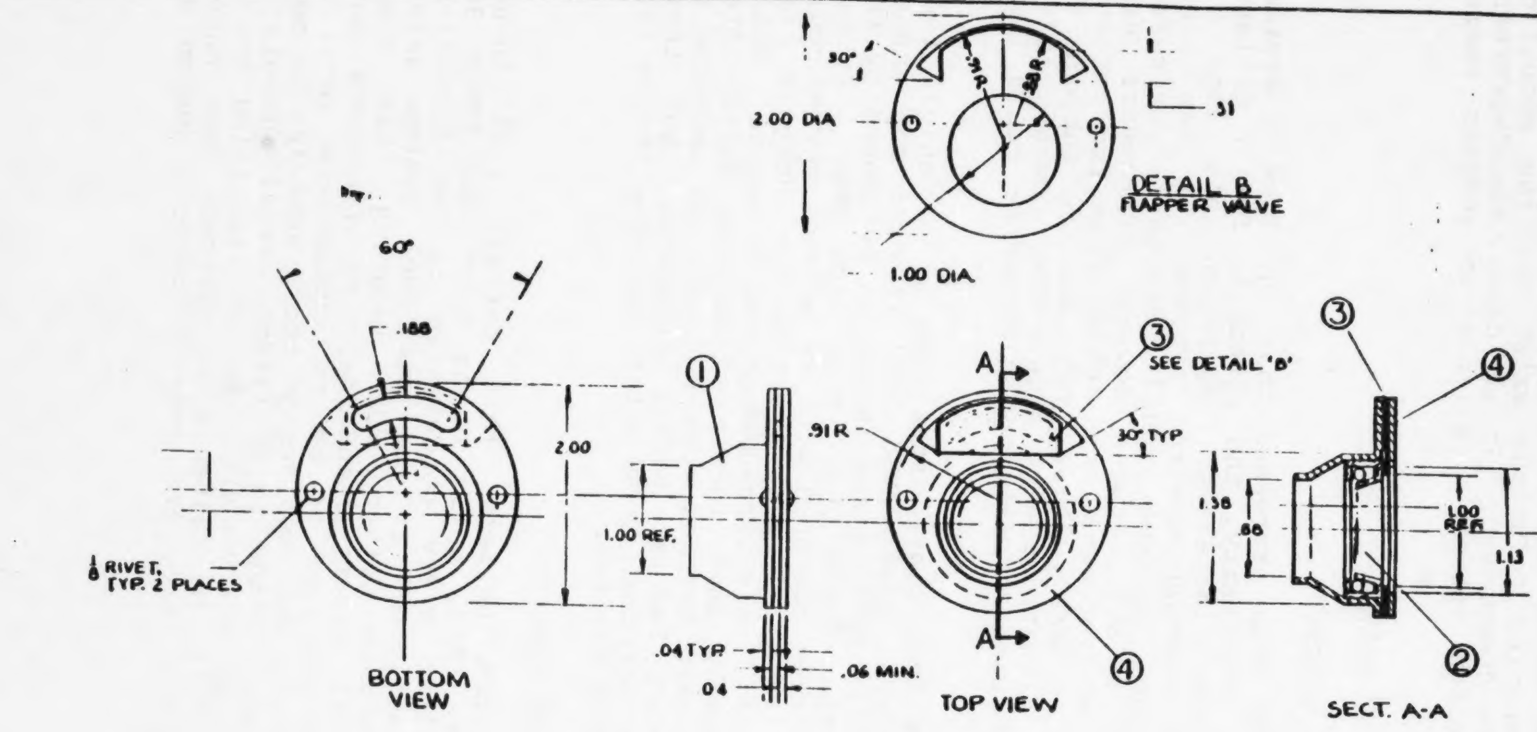
There have been several different designs suggested for such pressure relief devices. A sample design is shown in Figure 17 which would be incorporated directly into the design of the fillpipe so that the condition would be noticeable by the operator.[18] The operator would then be prompted to repair any problems in order to resume normal refueling actions. (The need for prompt repair would have positive safety and air quality implications.) As was shown in Figure 9, it might also be possible to incorporate the pressure relief function into some other component of the system such as the rollover valve. Any overpressure concerns can be eliminated through a simple pressure relief device such as these.

2. Pre-Refueling Overpressure Effects

Another potential safety issue raised relating to refueling operations has to do with the "U" bend in the "J-tube" fillneck seal. If the tank vent became blocked, and pressure built up substantially in the tank, upon removal of the fuel cap, the liquid gasoline which was left standing in the "U" bend could be spit back out the fillpipe.

This concern can be easily addressed by drilling a small hole in the bottom of the "U" bend (see Figure 4 and 5), which would allow any fuel left standing in the fillpipe subsequent to a refueling event to drain out into the fuel tank. Given the range of fuel dispensing rates seen in-use, this hole can be sized to quickly provide drain capacity and still provide the seal needed during refueling. Furthermore, the hole size can be sized so that no foreign object will block it during a refueling event. By evacuating the column of fuel left standing in the fillpipe, the potential for spitback to occur upon removal of the fuel tank cap would be eliminated. Fillpipes with a "J-tube" seal employing a drain hole have been tested. These tests show that these seals provide refueling emission control efficiencies comparable to those of mechanical seals.[16]

Figure 17


30°
2.00 DIA
.91R
.88R
.31
DETAIL B
FLAPPER VALVE
1.00 DIA
60°
.188
2.00
①
1.00 REF.
$\frac{1}{8}$ RIVET, TYP. 2 PLACES
BOTTOM VIEW
.04 TYP
.04
.06 MIN.
.91R
A
A
③
SEE DETAIL 'B'
30° TYP
④
TOP VIEW
③
④
1.38
.88
1.00 REF
1.13
②
SECT. A-A

NOTES:

1. △ REMOVE ALL BURRS AND SHARP EDGES. .01 R MAX OR CHAMFER
2. △ ROTARY SHAFT SEAL IS A PURCHASED PART. PART NO. TBD.

PART NO.	QTY REQD	DESCRIPTION	MATERIAL	SPECIF.
4	1	UPPER RETAINER	STEEL	
3	1	VALVE FLAPPER	VITON	
△ 2	1	ROTARY SHAFT SEAL		PURCHASED
1	1	LOWER RETAINER	STEEL	

NOZZLE SEAL/RELIEF VALVE
ASSEMBLY

MUELLER ASSOCIATES, INC Baltimore, MD
DATE 11/10/80 SCALE: FULL PAGE 1 OF 1.

3. Summary

The analysis presented above demonstrates that simple, straightforward engineering solutions exist for the specific concerns raised by the commenters. In all cases, manufacturers have a number of design options available to address these concerns.

V. In-Use Fuel System Safety

1. Summary of Concerns

Some concern has been expressed that any time a system increases in size or complexity, the potential for a failure within the system also increases. Applying this line of thinking to vehicle emission control systems, it has been suggested that onboard systems would inherently decrease overall fuel system safety because several components are larger and a few more components are needed than for current evaporative emission systems. In-use vehicles are subject to innumerable accident situations, and some concern exists as to whether or not an increase in component size/number could lead to safety problems.

Further, it has been stated that even if a vehicle fuel system is safe enough to pass FMVSS 301, it does not insure that it is free of all safety risks in-use as evidenced by the number of vehicle crash fires that occur each year. It has been argued that vehicles equipped with an onboard system could pass all FMVSS 301 tests and yet directionally increase risk in-use by some unquantifiable (presumably small) amount. Thus, it follows that because some in-use situations differ from FMVSS 301 tests, onboard systems must not only be designed to be capable of passing Federal safety standards, but these systems must also be designed so as not to increase in-use risk for fuel system related hazards.

2. Analysis of Issues

Fundamentally, EPA believes that overall risk in-use should not increase. And, while it is true that FMVSS 301 cannot protect against every conceivable in-use situation, manufacturers are motivated to consider fuel system safety implications for reasons other than insuring that their vehicles pass Federal safety standards. Manufacturers must determine what they consider to be an appropriate level of safety and in-use risk, and then design their vehicles to meet this level. Often this leads to different overall levels of safety in different vehicle models. Before discussing how to address this issue, it is valuable to discuss how safety concerns are integrated into the overall vehicle design and development process.

First, safety is an integral part of the design process and is normally not considered incrementally. However, managing risk involves a series of trade-offs, balances, and compromises with other key design criteria. Manufacturers choose not to make their vehicles free of all risk because of other valid design considerations such as performance, styling, weight, cost, and other factors. It is generally accepted that no technological constraints exist which would prevent the production of a nearly "fire-proof" vehicle, and certainly vehicles could be made safer than they currently are as evidenced by numerous "safety car" designs.[27] However, cost and other considerations are valid and they prevent "zero" risk (or a perfectly safe vehicle) from being considered appropriate. One analyst has stated, "It is definitely not reasonable to expect manufacturers to produce 'Sherman Tanks' ... as such vehicles would neither serve the needs of societal safety, mobility, or economy."[28]

This same logic and risk management process applies to fuel system safety. Factoring safety into fuel system design is a complicated process that involves numerous tradeoffs and compromises as above. Fuel system designs are not all alike, and fuel system safety considerations vary from one design to another. For example, fuel tank size and location on the vehicle have a substantial impact on a vehicle's safety during a collision. Rear fill tanks are in a more accident prone location than side fill tanks, and are usually located closer to the exterior shell of vehicle. Side fill tanks are generally considered safer than rear fill tanks, and consequently, rear fill fuel tanks are gradually being phased out of vehicle designs. However, it should be noted that this change over has not occurred immediately due to other design considerations such as cost and conflicting interaction with other aspects of the total vehicle design. A similar set of arguments can be made with plastic versus metal fuel tanks. These simple examples demonstrate how risks are managed relative to other considerations. Even current fuel systems could be safer but some risk is accepted.

Another interesting example lies in the area of fuel system external plumbing such as emission control vapor lines or external vent lines along the fillpipe. At one time added piping connections similar to the external vapor vent lines that appear on some of today's vehicles were characterized as an unacceptable added safety risk by General Motors.[29] After further testing and design, that same manufacturer incorporates an external vapor vent line into many of its current vehicle's fuel systems. With safety engineering and field testing any potential safety risks associated with these external vent lines has been managed.

This particular design change illustrates a very significant aspect of fuel system safety. Even though concern existed over the potential safety aspects of additional fuel system plumbing, the mere fact that these additional lines appear on today's vehicles confirms that safety concerns can be technically addressed if desired. Any perceived in-use risk can be managed. Safety does not have to be an obstacle to fuel system improvements or modifications. The technology to reduce safety risks is currently available, and the degree to which it is utilized depends on how much risk a manufacturer is willing to accept.

As illustrated in the discussions above, manufacturers accept or manage varying amounts of risk in order to strike a balance or compromise with all of the important design criteria. Clearly safer vehicles could be made, and the amount of in-use risk reduced. As considerations change, the amount of risk accepted may also change. Often the level of acceptable risk may be more constrained by in-use liability concerns than government safety tests. For example, crash testing results from NHTSA's new car assessment program show that the vehicles' ability to protect its occupants from injury vary by vehicle model.[30] Different vehicle models provide different levels of protection for the head, chest, and femur during barrier crash testing at 35 mph. Some manufacturers chose to incorporate safer designs on some models for liability and perhaps marketability reasons.

Similarly, the safety of an onboard system on in-use vehicles will depend on the design decisions made by the manufacturers. Onboard systems would increase the size and number of fuel system emission control components, and some concern has been expressed that the safety of these components in FMVSS 301 testing may not necessarily be indicative of in-use performance. However, adding these systems does not need to affect the level of risk a manufacturer is willing to or can afford to accept. As with any other system change, manufacturers would integrate onboard systems into their vehicles' fuel systems without increasing overall system risk, and clearly, there are no inherent technical constraints prohibiting them from doing so.

Further, there is little merit to the assertion that an onboard system must be inherently less safe than an evaporative emission system because it is more "complicated". Adding a few components and enlarging a couple of others presents no risk which cannot be managed to levels now deemed acceptable. As a matter of fact, many of the improvements recently implemented on passenger cars and light trucks have resulted in vehicles/systems which are increased in both safety and complexity. Consider for example advances made in vehicle/engine control systems. Electronic engine controls have increased vehicle engine complexity tremendously over previous systems, yet there is no evidence that these system "complications" have jeopardized safety. In fact, manufacturers are now considering computer controls for other vehicle systems such as the suspension and handling, with the direct purpose of improving vehicle safety.[31] A more complicated system does not imply a less safe one if given proper consideration during design.

As discussed in detail earlier, manufacturers have many options available in the design of an onboard system which can manage or eliminate any perceived increase in in-use risk. However, for manufacturers with special concerns regarding in-use safety there are even more design options available. Fail safe, redundant, or breakaway rollover valves could be used. The integrity of the critical portion of vapor line between the fuel tank and rollover valve could be assured through the use of steel braid covered rubber hose in key areas or steel tubing.[32] Both rubber and steel vapor line have been used on past vehicle models. If chafing of this critical portion of vapor line is a concern, the affected areas could be wrapped in a spiral spring for protection. Also, slack could be provided in this critical portion of vapor line to minimize the possibility of separation or rupture in an accident. Improved or additional fittings, adhesives, or clamps could be used to increase the strength of key vapor line connections between the fuel tank and the rollover valve. Concerns related to the charcoal canister can be addressed by using a reinforced canister shell or a protective barrier. While these may be somewhat extraordinary, this brief listing demonstrates that further design options are available which if used could improve safety over current vehicles.

In summary, manufacturers can manage their in-use risk and can choose to make an onboard system as safe as they deem appropriate. Onboard systems present no safety concerns which cannot be eliminated through proper design, and each manufacturer will develop the fuel system design which represents the best balance for each particular vehicle model, with full consideration of the safety risks and all other key factors.

3. Opportunities for Improvement

Implementing onboard controls could actually result in a net improvement in overall fuel system safety. Since manufacturers would need to redesign some aspects of their vehicles' fuel systems to incorporate onboard systems, the opportunity would be provided to reexamine other aspects of fuel system safety as well. Some of the potential fuel system improvements that could result from this reexamination include an acceleration of the transition from rear fill to side fill, integration of the current external vapor vent line inside the fillpipe, better placement of the fuel tank, or even improvement in the fuel tank integrity itself. Also, any number of other minor modifications or improvements in the fuel or emission control systems could be made which could enhance safety and performance and perhaps reduce cost. These include areas such as tank venting, purge valve operation, and eliminating many problems identified through owner complaints and other similar survey measures.

Also, it is likely that an onboard refueling control requirement would lead to a decrease in the amount of fuel spilled in-use and thus improve the overall safety of refueling events. In the certification refueling test, vehicles would have to be designed to accommodate a refueling dispensing rate near the high end of the present range of in-use values (8-10 gallons per minute) without any spillage or spitbacks. This is because any fuel spilled during the test is considered as part of the test results. Since one tablespoon of gasoline evaporates to a substantial amount of vapor (about 10 grams), almost any spillage that occurred during the certification test would result in a failure. Thus, the test procedure requirements will insure that manufacturers' fuel system fillpipe designs are capable of handling dispensed fuel at flow rates up to 10 gallons/minute without allowing any spitback. The use of these fillpipe designs are predicted to lead to a reduction in the amount of fuel spilled in-use. This is compared to some current vehicle fillpipe designs which have difficulty accepting fuel at the lower end of the in-use range (8-10 gpm) without spitback. To assure this benefit accrues in the long term, EPA is considering an in-use dispensing rate limit of 10 gallons per minute along with any onboard requirement.

Also, from the analysis presented above, it is evident that implementing onboard controls would provide at least three other direct safety benefits over present systems. First, depending on the design used, adding a rollover protection device may improve the safety of present fuel tank systems which use a 1/2" external vent line without rollover protection. Second, adding a rollover valve may enhance the safety for those vehicles which now use a limiting orifice for rollover protection, since a rollover valve will provide a positive seal in lieu of the "controlled leak" approach provided by the limiting orifice. Last of all, it should be noted that refueling vapors are currently vented to an area which poses somewhat of a safety hazard. This is because the potential exists for refueling vapors to ignite inadvertently as they escape from the fillneck opening. However, as onboard controls are phased in, and more and more vehicles route refueling vapors away from the fuel pump operator to a safer point (the charcoal canister) the overall risk involved in refueling a vehicle will be reduced.

Finally, to address any special concerns regarding onboard system crashworthiness and to perhaps improve crashworthiness over current vehicles, there is an alternative onboard system design available which manufacturers may elect. As is shown in Figure 18, this system is similar to Figure 4, except all the needed valves (rollover, vent, liquid/vapor separator) are built into the top of the fuel tank, instead of externally.

A solenoid activated rollover valve could be used (Figure 19) which is located on top of or inside the fuel tank.[33] This valve would normally be closed except during refueling when it would be electronically opened by a switch located near the opening of the fillpipe. The switch could be activated either by the opening of the door over the fuel cap or removal of the fuel cap itself (see Figure 20).

Yet another approach is a mechanical ball valve. This device would normally remain open to provide a clear vapor passage. However, in the event of a rollover accident gravity causes a metal ball to roll into a fitted seat and seal off the vent line. One variation on this design (see Figure 21) would be simple mechanical ball valve built in combination with other needed valves.[15]

As is shown in Figure 18, this onboard system design may need a fill limiter to allow for normal refueling operations (i.e., automatic shut-off) and to prevent overfilling the tank during full refills. A sample design is shown in Figure 22.[33] The operation of the fill limiter is quite simple. When the tank is full the float rises in the fill limiter and closes off the refueling vent line. This causes pressure to rise in the tank, subsequently fuel runs up the fillpipe and activates the nozzle automatic shut off mechanism. While incorporation of a fill limiter is quite simple from an engineering perspective, the design would have to incorporate a "soft close" to avoid back pressure "spikes" and possible spills at the end of a full refill.

From a safety perspective this alternative is attractive because all the external components are either removed or mounted in a more protected location. The external vent line (Figure 1) can be eliminated and the other system valves and vapor lines are moved away from the vehicle shell to a more protected area within the vehicle body. Also, no vapor line exists between the fuel tank and the rollover valve, so vapor line integrity and connections are less critical.

Finally, depending on how high a priority a manufacturer assigns to safety or if significant in-use risk is perceived, a collapsible bladder tank design could be used to meet the onboard requirement. Bladder tanks could lead to a substantial improvement in fuel system safety by providing an additional shell of protection to help reduce fuel spillage in case of an

Figure 18

ALTERNATIVE INTEGRATED EVAPORATIVE/REFUELING SYSTEM

TANK MOUNTED VALVES
REAR MOUNTED CANISTER
J-TUBE SEAL

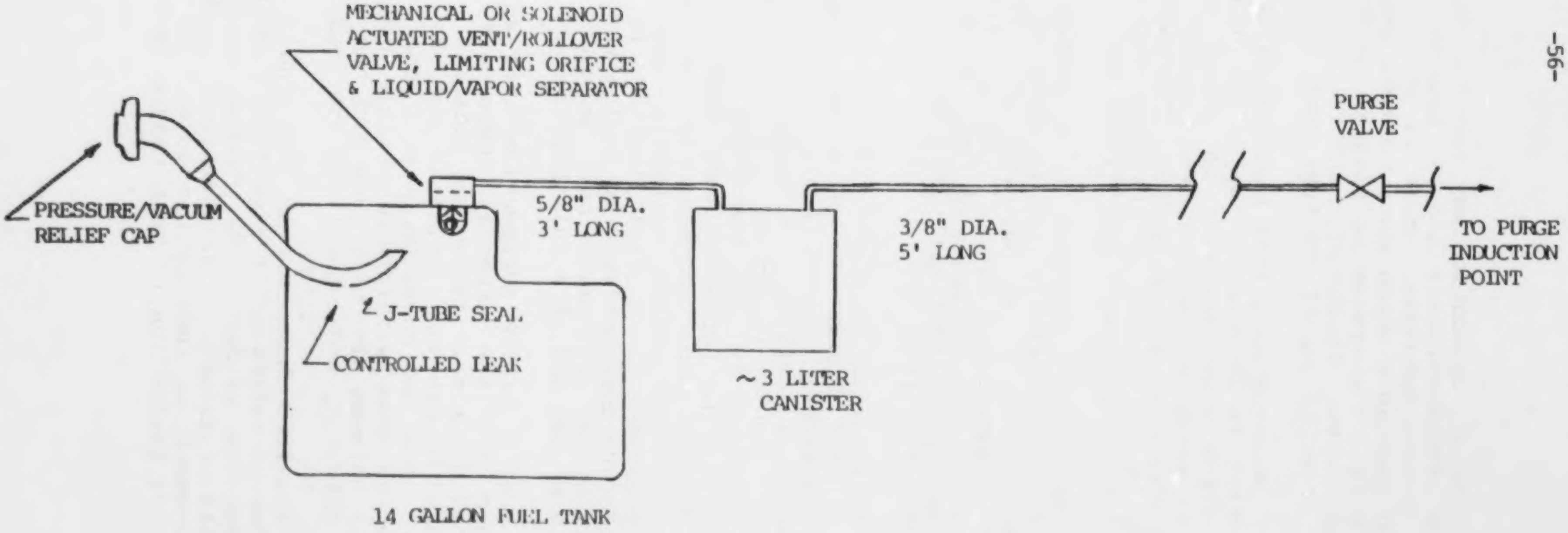
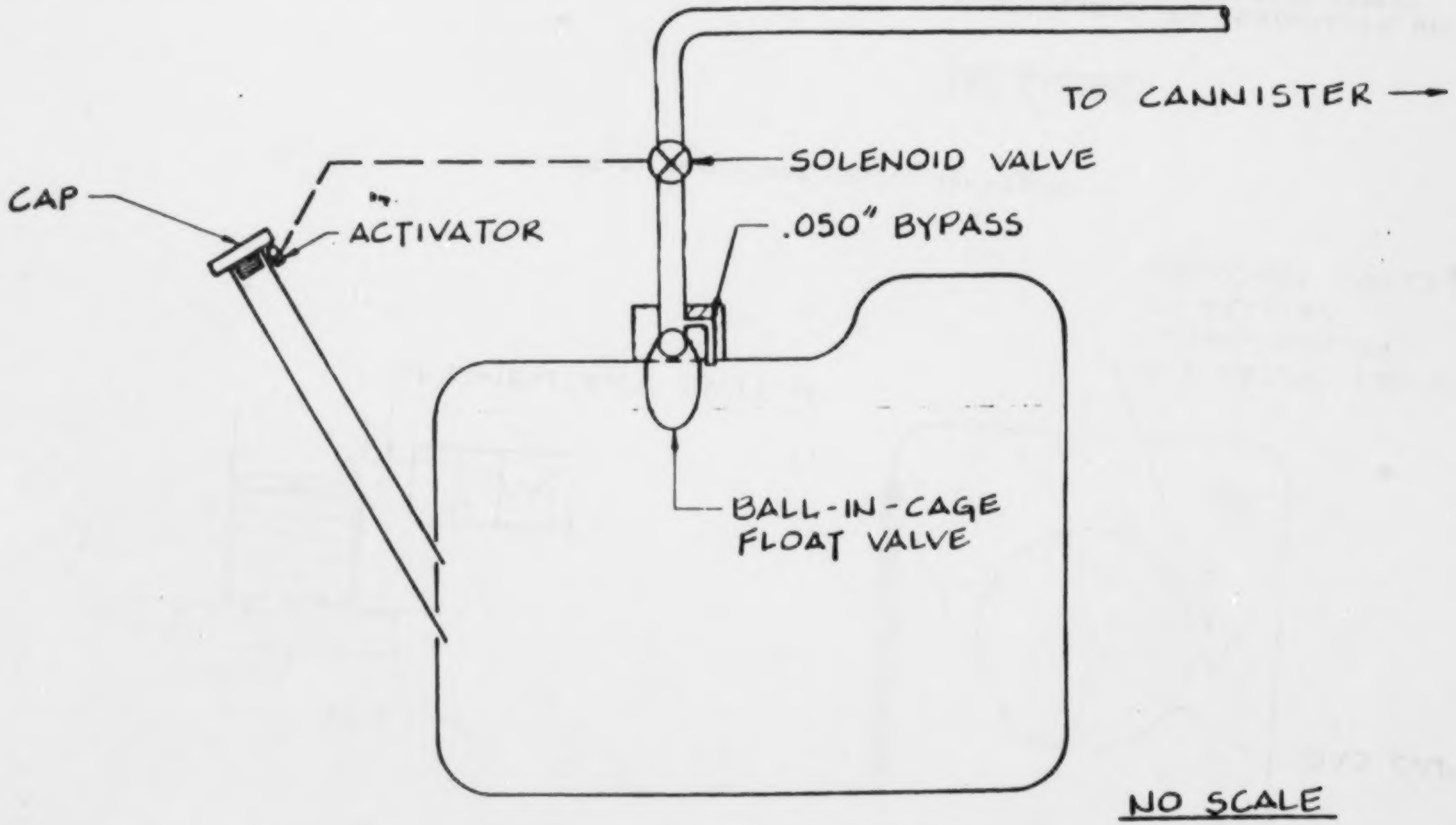

MECHANICAL OR SOLENOID ACTUATED VENT/ROLLOVER VALVE, LIMITING ORIFICE & LIQUID/VAPOR SEPARATOR
PURGE VALVE
PRESSURE/VACUUM RELIEF CAP
5/8" DIA. 3' LONG
3/8" DIA. 5' LONG
TO PURGE INDUCTION POINT
J-TUBE SEAL
CONTROLLED LEAK
~3 LITER CANISTER
14 GALLON FUEL TANK

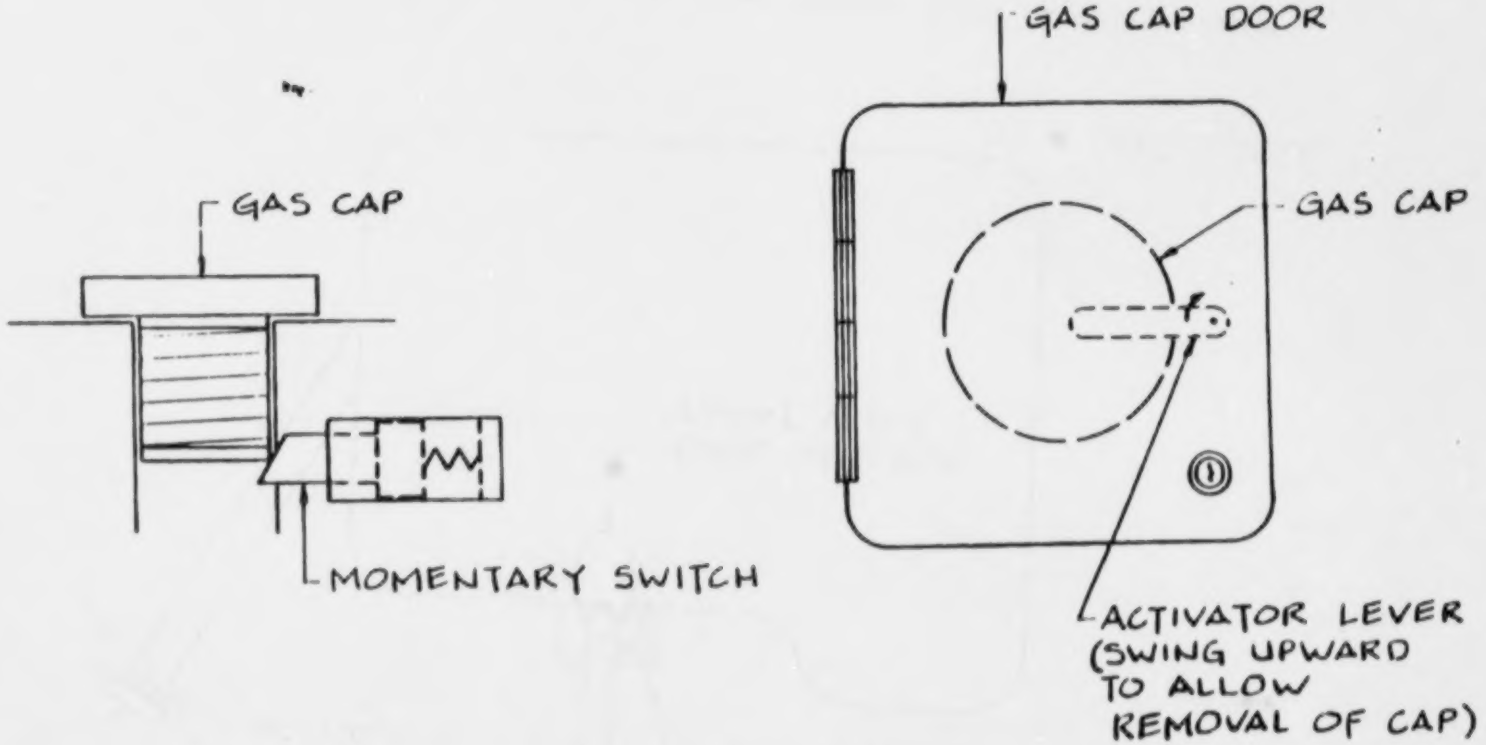
Figure 19


TO CANNISTER →
CAP
ACTIVATOR
SOLENOID VALVE
.050" BYPASS
BALL-IN-CAGE
FLOAT VALVE
NO SCALE

SCHEMATIC OF POTENTIAL ONBOARD VAPOR RECOVERY SYSTEM

MUELLER ASSOCIATES, INC.
1401 S. EDGEWOOD STREET
BALTIMORE, MARYLAND 21227
JANUARY 31, 1986

Figure 20


GAS CAP
MOMENTARY SWITCH
GAS CAP DOOR
GAS CAP
ACTIVATOR LEVER (SWING UPWARD TO ALLOW REMOVAL OF CAP)

POTENTIAL MOMENTARY SWITCH LOCATIONS

NO SCALE

MUELLER ASSOCIATES, INC.
1401 S. EDGEWOOD STREET
BALTIMORE, MARYLAND 21227
JANUARY 31, 1986

Figure 21

COMBINATION VALVE

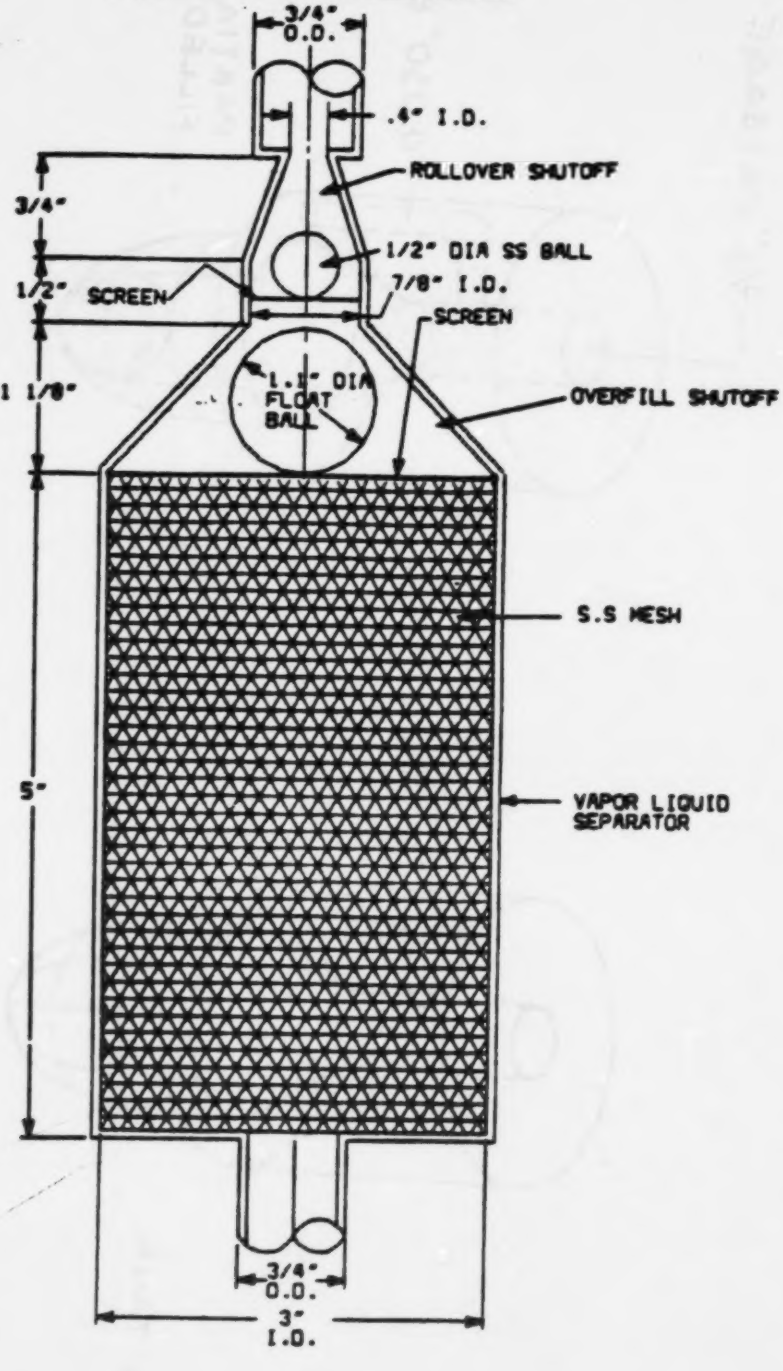
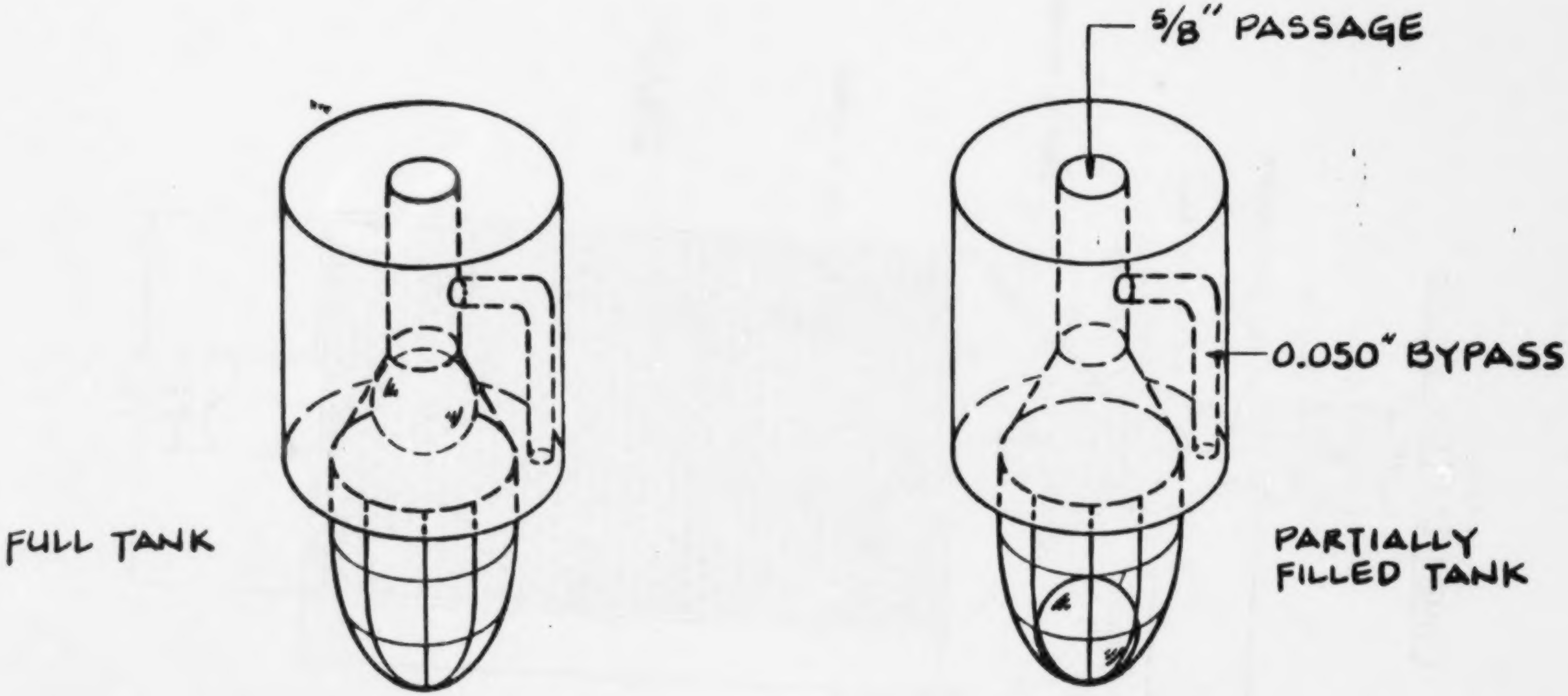

3/4"
O.D.
.4" I.D.
ROLLOVER SHUTOFF
3/4"
1/2" DIA SS BALL
1/2"
SCREEN
7/8" I.D.
SCREEN
1 1/8"
1.1" DIA
FLOAT
BALL
OVERFILL SHUTOFF
S.S MESH
5"
VAPOR LIQUID
SEPARATOR
3/4"
O.D.
3"
I.D.

Figure 22


5/8" PASSAGE
0.050" BYPASS
FULL TANK
PARTIALLY FILLED TANK

BALL-IN-CAGE FLOAT VALVE

NO SCALE

MUELLER ASSOCIATES, INC.
1401 S. EDGEWOOD STREET
BALTIMORE, MARYLAND 21227
JANUARY 31, 1985

accident. Also, a bladder tank could eliminate essentially all of the safety concerns raised regarding control of refueling emissions. This is because a vapor space would not be present in a bladder tank, and without a vapor space, refueling emissions would not occur. Thus neither a refueling emissions canister, external plumbing, or a rollover valve would be needed. It might even be possible to eliminate the present evaporative system and enhance safety even more. Also, bladders should be an attractive option for those who claim high costs or packaging problems with canister-based onboard systems. EPA is quite interested in collapsible bladder tanks as an option to canister-based onboard systems. This analysis of design and in use safety issues and the associated costs and leadtime is not directly applicable to collapsible bladder tanks. However, EPA plans to further explore the cost and technological feasibility of bladders as well as their safety and emission benefits.

In conclusion, the information and rationale presented above refute the assertion that adding an onboard system would directionally increase in-use risk, even if only by some unquantifiable (presumably small) amount. Any perceived risk is manageable, and furthermore, it appears that the net effect of an onboard refueling control requirement could be a potential increase in fuel system safety. As discussed above, and in Section IV there are numerous design alternatives to address the safety concerns raised. To varying degrees all options have the potential to improve the safety of fuel systems in-use.

VI. Cost and Leadtime Considerations

The comments received regarding onboard vapor recovery systems also addressed the cost and leadtime implications of implementing such controls. More specifically, several of the comments addressed onboard safety costs in some form (usually addressing hardware costs), and several commenters expressed some concern over EPA's leadtime estimate. An analysis of the costs and leadtime necessary to implement onboard controls safely is an integral part of the overall evaluation of the feasibility of this control approach. As was mentioned above, cost is one of the other key considerations which is often balanced carefully against safety concerns, and the costs needed to implement onboard systems safely must be reasonable relative to other safety costs and the overall costs of onboard systems. Further, the analysis must carefully consider the manufacturer leadtime needed to implement onboard controls on their production vehicles. This includes the time needed to identify, evaluate, and address all safety concerns and to comply with the test requirements prescribed in FMVSS 301.

The first portion of this section addresses onboard safety costs; the second discusses leadtime and describes the basis for EPA's leadtime estimate. Some of the cost figures cited in the safety cost analysis are drawn from a broader EPA analysis which develops total onboard system costs in 1984 dollars.[17]

A. Safety Costs

As is evident from the discussion presented in Section IV, the costs needed to implement onboard controls safely fall in several areas. R&D type costs will be incurred, some new or modified components will be needed which may slightly affect vehicle operating costs, and safety certification testing will be necessary. However before beginning a discussion of these costs, it is valuable to discuss how the FMVSS 301 standards and EPA's evaporative emission control requirements impact onboard safety costs.

The control of refueling emissions through an onboard system would not be the first Federal regulation to require an investment to improve fuel system safety. The first fuel system integrity standards (FMVSS 301) were implemented by NHTSA for 1968 vehicles, and since then there have been 2 major additions to these requirements. Each of these new requirements has caused a small cost increase, but each has also led to an improvement in fuel system safety on in-use vehicles. In the mid 1970's, FMVSS 301 was substantially upgraded to extend the coverage of impact types to include rollover events and, rear end and side collisions. A 1983 NHTSA Technical Report describes the nature of the modifications made in response to the upgrading of the standard and estimates the costs incurred by vehicle manufacturers in order to meet the revised standard and provide a higher level of in-use assurance.[21]

Table 3 describes modifications that were made to 1977 model year vehicle fuel systems in response to the increased requirements of FMVSS 301. These modifications ranged from minor changes such as the slight revision of mounting bolts or clips to more major ones such as recontouring the fuel tank. Based on information submitted to NHTSA by vehicle manufacturers, the average (sales-weighted) cost increase required to make these modifications was $4.60 per vehicle.* These modifications were also estimated to increase vehicle weight slightly (an average of three pounds per vehicle), which would tend to marginally increase the amount of fuel consumed over the life of the vehicle (about 3 gallons of fuel). When these two costs are added, NHTSA estimated the total safety cost resulting from the 1977 revisions to FMVSS 301 averaged about $8.50 per vehicle (1982 dollars).

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* A Bureau of Labor Statistics analysis estimated that vehicle costs incurred to meet the 1977 revision to FMVSS 301 were $4.70 and costs to meet the 1976 revision to the standard (added rollover test) cost $2.10.[34,35]

Table 3

Summary of Vehicle Modifications in Response to 301-77

Vehicle Components

Fuel System Components	Modification(s) to Improve Crashworthiness
Fuel Tank	- Increase gauge of tank material - Add protective shield - Recontour to minimize contact/puncture by other adjacent vehicle components. - Strengthen/shield filler neck - Increase strength of solder/weld seams - Strengthen mounting by adding brackets, revising mounting bolts, increasing torque of mounting straps - Strengthen filler cap seal, improve impact resistance
Fuel Gauge Sensor	- Strengthen mounting
Fuel Lines	- Recontour
Fuel Vapor Lines	- Recontour, revise, revise clamps
Fuel Pump	- Provide shield

Other Vehicle Components Changed to Improve Fuel System Integrity

Rear Floor Pan/Support Rails/Wheel Housing	- Revise, add supports
Rear Suspension (Springs, Shock Absorbers)	- Change support brackets, revise mounting bolts, revise mounting procedure, and shield
Rear Axle Assembly	- Minor changes in contour of lines, screw heads, mounting clips, recontour vent cover
Rear Axle Assembly	- Revise hinge assembly
Seat Belt Brackets	- Revise anchorage
Engine Mount	- Slight revision
Power Steering Pump Bracket	- Slight revision

Based on an evaluation of in-use accident information for 1977 and later model year vehicles, NHTSA's 1983 Technical Report also estimated that the upgrading of FMVSS 301 would in the long term annually prevent 400 fatalities, 630 injuries, and 6500 post crash fires. This indicates that FMVSS 301 has been effective in substantially improving many aspects of overall fuel system safety and that these improvements were purchased relatively inexpensively.

The second area of interest is the effect of current evaporative emission systems on potential onboard system safety costs. As was described in Section III of the report, an onboard system is in many ways an extrapolation of current evaporative emission control technology and the two systems are quite similar. Many of the control techniques and basic system components used would be similar, and the same system and vehicle assembly approaches could be used. In fact, many manufacturers will likely integrate their refueling and fuel tank evaporative control systems. All current vehicle fuel systems incorporate fairly sophisticated evaporative emission control systems. Since these fuel systems have all been designed to meet the most recent and most stringent version of FMVSS 301 and also provide a high level of in-use safety performance, it follows that a thorough evaluation of the potential safety implications of evaporative control systems has already been conducted. Since onboard systems are basically extensions of evaporative emission systems, clearly many of the safety design considerations associated with onboard systems related to passing FMVSS 301 or providing in-use assurance have already been resolved or at least addressed in evaporative emission system designs. Consequently, much of the "ground work" required to insure onboard safety has already been performed. Therefore, it is important to keep the magnitude of the onboard safety design process in perspective, because clearly much of the safety technology needed for onboard is simply an extension of that which already exists.

Remembering the relatively inexpensive and yet effective nature of current fuel system integrity measures and the "incremental" nature of onboard safety in terms of the magnitude of the task and actual cost relative to evaporative systems, it is now possible to describe the components which factor into onboard safety costs. Basically, the integration of safety into a fuel system incorporating an onboard controls involves four types of costs. These four costs are for 1) design and development (R&D), 2) specific hardware, 3) safety testing, and 4) weight penalty (or added fuel consumption). The paragraphs that follow describe how each of the cost components are affected by onboard safety.

To begin with, some research and development will have to be performed to safely integrate onboard controls into vehicle fuel systems. EPA has estimated that the total design and development cost required to incorporate onboard systems in vehicle fuel systems is about $112,000 per family or in the range of $0.35 to $0.55 per vehicle (passenger car and light truck). This cost is for any development effort involved in combining the components of an onboard system with the rest of the vehicle to form a unit that interacts safely and effectively. Because safety is evaluated inherently in the design and development process and yet is only one part of the total effort, only a fraction of the total cost should be directly allocated to safety. Also, because much of the safety related system development work has already been completed it is not unreasonable to expect that onboard safety development costs would only be a small fraction of the total cost in this area. In addition, because of the incremental nature of the onboard system, much of the research and development that went into making evaporative control systems safe can be applied directly to onboard controls.

Given that manufacturers are designing an onboard system in the context of many requirements and certain design features serve multiple functions, it is very difficult to isolate the level of expenditures directly attributable to safety. For this analysis it was assumed that about 20 percent of R&D expenditures relate to safety, which translates to about $0.10 per vehicle. However, total onboard cost is quite insensitive to this assumption, even if the safety related development costs were tripled, per vehicle costs would increase by only one percent.

The second component of onboard safety costs relates to specific hardware that may be required to insure fuel system safety. EPA has estimated costs for three specific items which have been identified as potential components to be included as part of the onboard system design explicitly for safety reasons. These three items are 1) a rollover valve, 2) a pressure relief mechanism, and 3) fuel system modifications necessary to safely incorporate a rollover valve, pressure relief mechanism, or other onboard hardware. EPA has estimated the cost of a solenoid rollover valve (like the one shown in Figures 19 and 20) to be $4.60.[17] This price included the cost of the valve, an actuator located at the fillcap, and the necessary wiring and connectors. Manufacturers estimate the cost of a valve assembly similar to that described by EPA's cost estimate would be in the range of $5.00 to $6.00. It should be noted that these estimates are for the most complex rollover valve type, and that the cost of a simpler valve assembly such as the fillneck mounted type (see Figures 9-15) is estimated to be more in the $3.00 to $4.00 range. The available information indicates that an appropriate rollover valve cost falls into a range of $3.00 to $6.00.

The second safety hardware cost is for a pressure relief mechanism. This mechanism would only be needed for onboard systems incorporating a mechanical fillneck seal, and consequently not all vehicles would require its use. However, for those systems that would require a pressure relief mechanism, EPA has estimated that this device would increase system costs by approximately $0.50. This estimate is based on pressure relief mechanisms currently used in automotive applications which perform the same basic function and are similar in complexity.[36]

The final onboard safety hardware cost accounts for any fuel system modifications that would be necessary in order to safely accommodate any onboard control hardware. For example, a vehicle's fuel tank or fillpipe might have to be re-shaped or modified in order to accept a rollover valve. Also, for safety reasons, some slight re-routing of the fuel system's vapor lines may be required. EPA has estimated a total modification cost to be $0.50 per vehicle. Only part of this total cost would be required for safety purposes. However, because safety inherently enters into the decision to make any modifications, it is difficult to access what part of the total modification cost should be allocated to safety; perhaps half or more ($0.25 to $0.30 per vehicle) could be considered as driven by safety related concerns.

Summing up the three individual safety hardware costs yields a total estimated figure in the range of $3.25 to $6.80. However, this cost estimate does not include manufacturer overhead and profit. In order to obtain the retail price equivalent cost, these estimates must be multiplied by a markup factor. Presently, a markup factor value of 1.26 appears representative.[37] Therefore, after inclusion of the markup factor, a total retail price equivalent safety-related hardware cost falls within the range of $4.10 to $8.60.

The third component of safety costs accounts for any safety crash testing that would be necessary. EPA has estimated the cost of FMVSS 301 crash testing to assure fuel system integrity for onboard systems to be about $34,000 per bodyline/style or about $0.12 per vehicle.[38] This estimate is based on four tests for FMVSS 301 only required per body line/style with two vehicles required for each sequence of four tests. Clearly safety crash test costs are very minimal in the long term and do not pose an obstacle to the adoption of onboard controls. In some cases these costs may be higher but even if total costs were double the estimate, the overall per vehicle cost would rise by less than one percent. Also, costs could be lower if FMVSS 301 test were combined with crash testing required for compliance with other safety standards.

The fourth component of safety costs is the estimate of the added fuel consumed over the life of the vehicle due to the increase in vehicle weight resulting from added safety hardware. The amount of weight added to a vehicle for a rollover valve and pressure relief mechanism is very small (0.4 lbs), and EPA estimates that only about $0.25 in added fuel costs will result from their inclusion into the onboard system.[17]

A total onboard safety cost is calculated by summing all four individual component costs. Total capital costs per family average about $56,000. The per vehicle safety-related costs range from $4.50 to $9.00, or about 25 percent of EPA's estimate of the total cost, depending on the type of rollover valve used.

One final point needs to be made with regard to these safety cost estimates. To the degree that manufacturers take the opportunity introduced by an onboard requirement to further reduce in-use risk beyond that now accepted with present systems, some additional costs might be involved which have not been identified or quantified. On a fleetwide basis these would be quite small. Also, it should be noted that the added benefits of these measures have not been included either.

EPA estimates safety related onboard costs to be $4.50-9.00 per vehicle. While there is some uncertainty in the development cost portion of the estimate, the total range shown here is quite insensitive to any error. These costs are quite similar to those previously incurred by manufacturers to insure fuel system safety. Many of the potential problems related to implementing onboard systems safely have already been considered in the design and development of present evaporative systems. The manufacturers previous experience in implementing evaporative systems safely and the incremental nature of onboard systems reduces costs and the level of potential problems. This analysis demonstrates that high levels of in-use fuel system safety can be achieved at low cost, and there is no need for a manufacturer to "cut corners" on onboard safety to reduce costs.

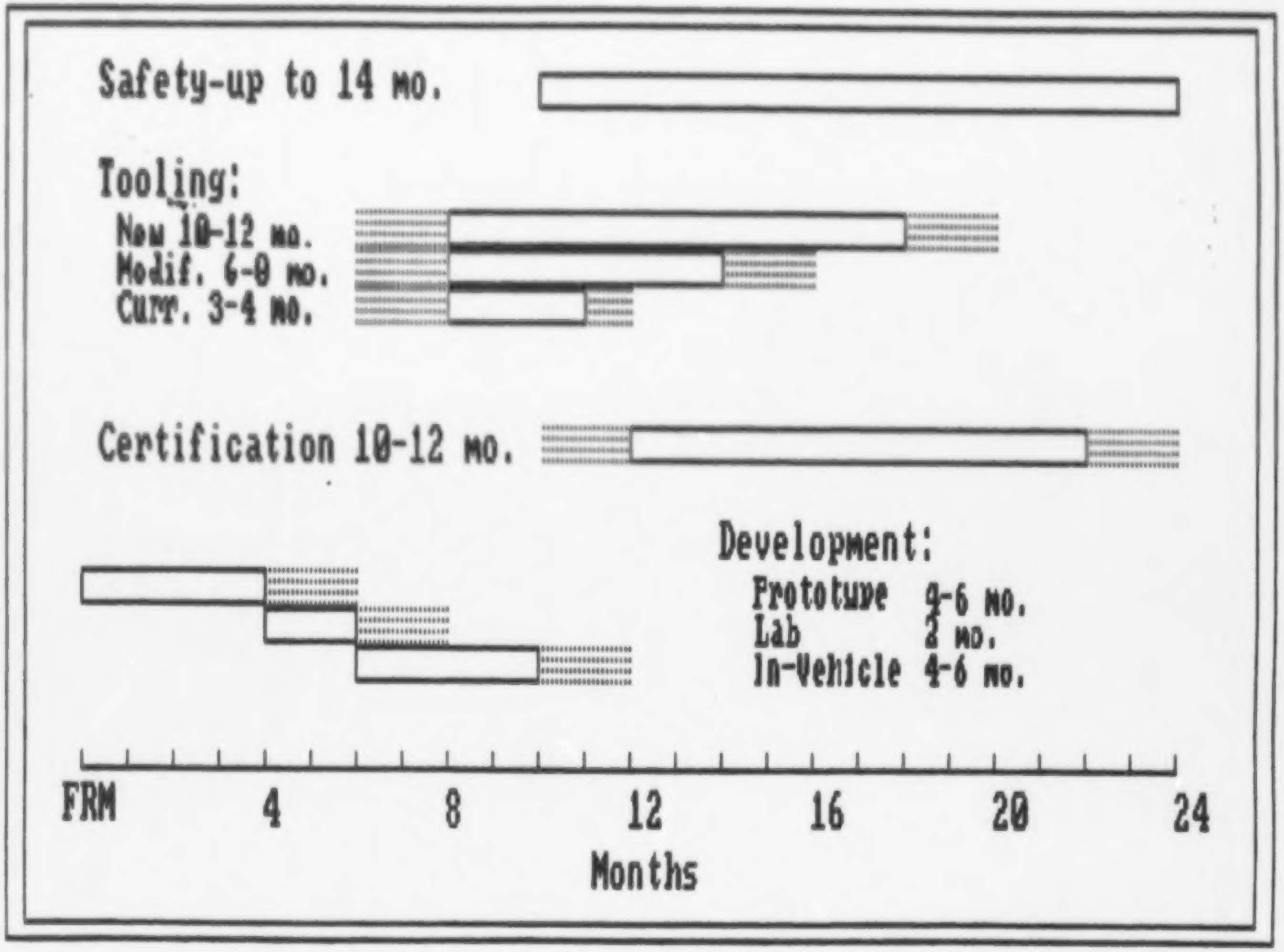
B. Leadtime

If EPA were to implement an onboard requirement, it would be necessary to allow a sufficient period of leadtime between the date the rule is promulgated and the model year the systems are to be required on production vehicles. This leadtime is provided so that manufacturers will be able to adequately prepare for the requirement through system design, development, testing, tooling, certification, and safety evaluation. Some of the tasks involved in the preparation process could be worked on simultaneously, while some tasks cannot begin before others are complete. While EPA estimates that none of the individual tasks require more than twelve months to complete, due to the sequential nature of some of the tasks, a leadtime period of approximately 24 months will be required by manufacturers.

Figure 23 shows how the individual leadtime components result in a total estimate of 24 months. First, four to six months are included for manufacturers to develop and optimize working prototype systems applicable to all of their different vehicle models. This is not at all unreasonable given the fact that working prototypes already exist and many manufacturers have evaluated these or their own prototype to some degree. Not all manufacturers have developed working prototype onboard systems, but the technology required to develop such systems is readily available and in-depth technical descriptions of such systems have been described in publicly available literature. Four to six months should be adequate time for these manufacturers to develop and evaluate prototype systems.

Once the prototype development is complete, initial durability testing of the prototype could be conducted under laboratory conditions. This laboratory testing is not expected to last more than two months.

Following laboratory testing, three separate actions can begin simultaneously. These three tasks are: 1) in-vehicle testing, 2) safety optimization, and 3) tooling and prove out of the overall control system through efficiency and durability verification. Similar in-vehicle testing programs have required four to six months for completion. Safety evaluation is the second task which could begin subsequent to the completion of the prototype laboratory testing. Safety evaluation would involve the use of computer crash simulation models and vehicle crash testing (four tests per body line/style) to verify the crashworthiness of the vehicle's modified fuel system. Because this evaluation could begin immediately after the completion of laboratory testing, a full 14 months of leadtime would be available to manufacturers if needed to perform this task. Based on discussions with NHTSA, 6 months is normally enough time to complete a safety evaluation. Therefore, 14 months appears more than adequate to perform the necessary safety optimization and testing for a manufacturer's product line. Tooling could also begin once laboratory testing is complete. Figure 23 shows EPA's estimate that tooling could require as little as 3 months and as much as 12 months depending on the magnitude of the task. Different factors are weighed before a manufacturer commits to various tooling changes. Manufacturers can commit to some tooling changes for onboard controls immediately after the in-vehicle testing (e.g., purge valves), whereas they may choose to wait until after safety analysis before committing to other tooling changes (e.g., rollover valves). However, in an overall sense, 12 months would provide manufacturers with enough time to delay some tooling changes and still complete the task well within the 24-month leadtime.



▤ Denotes scheduling flexibility.

FIGURE 23 ONBOARD LEADTIME

The only other process which requires completion within the 24-month leadtime period is emissions certification. EPA has found from past experience that a manufacturer normally requires between 10 to 12 months to certify its product line.[39] This estimate is based on a 10 month engine family certification schedule which allows time for durability, emission data, fuel economy, and confirmatory testing. Because certification cannot begin prior to the completion of in-vehicle testing, certification is critical path, and EPA estimates a total leadtime period of 24 months will be needed overall.

Twenty-four months of leadtime is quite reasonable, especially since most of the fundamental development work is already complete. Onboard system prototypes are presently available, and many aspects of the system's performance have already been tested and proven to be effective. Also, because onboard control technology is incremental in nature to evaporative emission controls, there is no need to design and develop entirely new systems. As a matter of fact, many of the critical onboard design issues have already been incorporated into current fuel system designs with the inclusion of evaporative emission control systems. For example, evaporative emission control systems have already added the following to fuel systems: vapor vent lines, vapor storage device, canister purge capability, and corresponding safety provisions associated with each of these additions. Since much of the development work is already complete, implementing onboard systems should be no more of a problem to vehicle manufacturers than was implementing evaporative emission control systems.

EPA's 24-month leadtime estimate is supported by past experience with three previous evaporative emission rulemakings. These rulemakings included the original 1978 6.0 g/test LDV/LDT evaporative emission standard which was implemented with just 12 months of leadtime, the 1981 2.0 g/test LDV/LDT evaporative emission standard which was implemented with 24 months of leadtime, and the 1985 HDGV evaporative standard which was implemented with 24 months of leadtime. In each of these three rulemakings, manufacturers faced leadtime factors identical to the ones that would accompany an onboard requirement, including safety. Since manufacturers were able to safely and effectively integrate evaporative emission controls into their vehicles' fuel systems with 24 months of leadtime, and since the magnitude of the onboard implementation task is similar, this suggests that manufacturers should also be able to safely and effectively integrate onboard into vehicle fuel systems with 24 months of leadtime.

As far as safety development and evaluation is concerned, EPA's leadtime estimate is also supported by the past experience of NHTSA in implementing the various versions of

FMVSS 301. Table 4 shows the chronological history of FMVSS 301. The original 1968 FMVSS 301 applicable to passenger cars was implemented with less than 12 months of leadtime. When the standard was revised for 1976 model year passenger cars, 17 months of leadtime was provided. For 1977 model year passenger cars, manufacturers had to contend with the most substantial upgrade to the standard, and this was accomplished with only 29 months of leadtime, and only 12 months between new requirements. Also, beginning in the 1977 model year, FMVSS 301 was extended to include light trucks. This extension involved a 29-month leadtime period with further crash requirements in effect 12 months later, thus requiring recertification. Finally, in 1977, FMVSS 301 was extended to include school buses (with a GVWR greater than 10,000 lbs), and this requirement was implemented with 17 months of leadtime. This experience indicates that 24 months of leadtime allows manufacturers sufficient time to factor in safety.

Based on the information provided above, 24 months appears to be adequate time to implement onboard controls, with full consideration of all safety concerns. Because safety evaluation can proceed in parallel to three other tasks, more than a year is available for computer simulation and actual safety crash testing. This allows adequate leadtime to properly integrate safety into onboard systems especially since manufacturers can utilize and expand safety technology used in current evaporative emission control systems to develop effective onboard systems. Also, much of the safety development which would be required has already taken place with the identification and resolution of such potential safety issues as rollover protection and fuel tank pressure relief. Consequently, a 24-month leadtime period would provide manufacturers with sufficient opportunity to develop safe and effective onboard systems.

While this analysis indicates that the current leadtime estimate of 24 months is reasonable for most if not all vehicle models, EPA is sensitive to manufacturers concerns regarding leadtime requirements. Public comments regarding EPA's 24-month leadtime estimate were submitted as part of comments on EPA's original Gasoline Marketing Study (July 1984).[40] While most commenters did not object to the 24-month leadtime estimate presented in the Gasoline Marketing Study, auto manufacturers felt that a 24-month leadtime was insufficient to implement onboard controls. The leadtime periods suggested by these commenters ranged from three to six years. Those commenters suggesting that four or more years would be necessary also suggested that onboard controls should be phased-in gradually as normal vehicle model redesign and turnover occurs. Using this approach, implementing onboard controls would be less burdensome and would allow extra time to deal with implementation or packaging problems on unique vehicles. However, it is worth noting that comments received

Table 4

Chronology of FMVSS 301 Requirements

Model Year Requirement	Vehicle Type	Promulgation Date	Effective Date	Leadtime (Months)	Time Since Last Requirements
1968[1]	PC	2-3-67	1-1-68	11	
1976[2]	PC	3-21-74	9-1-75	17	7 2/3 yrs.
1977[2]	PC	3-21-74	9-1-76	29	12 mos.
1977[2]	Class 1 LDT	3-21-74	9-1-76	29	
1978[2]	Class 1 LDT	3-21-74	9-1-77	41	12 mos.
1977[2]	Class 2 LDT	3-21-74	9-1-76	29	
1978[2]	Class 2 LDT	3-21-74	9-1-77	41	12 mos.
1977[3]	School Buses	10-15-75	4-1-77	17	

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[1] Motor Vehicle Safety Standard No. 301, Fuel Tanks, Fuel Tank Filler Pipes, and Fuel Tank Connections - Passenger Cars; 32 FR 2416, February 3, 1967, Part 571; S 301-1.

[2] Federal Motor Vehicle Safety Standard No. 301, Fuel System Integrity, 39 FR 10588, March 21, 1974.

[3] Federal Motor Vehicle Safety Standard No. 301, Fuel System Integrity, 40 FR 48352, October 15 1975.

from the manufacturers suggesting the need for a longer leadtime were not supported with any compelling arguments which would substantiate the insufficiency of a 24-month leadtime.

While the analysis above indicates that approximately 24 months of leadtime should be sufficient, there are some factors which must be considered but are difficult to factor into the analysis. First, as was mentioned above, some manufacturers have not developed working onboard prototypes due to resource or facility constraints and the possibility exists that these manufacturers will take no definitive action on systems development prior to a final action by EPA. Some have commented that these manufacturers should not be penalized because of this and may require a greater amount of leadtime. Second, vehicles with atypical duty cycles (ambulances, mail trucks, etc.) may require more leadtime to implement onboard controls safely. Vehicles assembled by secondary manufacturers such as recreational vehicles and airport mini-buses could also require more time especially if adding an onboard system requires other vehicle changes. Finally, more leadtime may be necessary because manufacturers may not have the test facility and safety engineering resources to effectively comply with multiple vehicle safety standard requirements concurrently. A similar concern may exist for emissions recertification since manufacturers would in most cases have to recertify virtually all gasoline powered vehicles for exhaust and evaporative emissions in addition to the new refueling requirement. Because of these concerns, more leadtime may be necessary for the implementation of safe onboard control systems.

EPA is committed to providing manufacturers the leadtime necessary to implement onboard controls safely and effectively. Consequently, EPA is open to considering the need for more leadtime and/or a short phase-in period for onboard controls. Such a phase-in period would provide manufacturers with additional time to solve any onboard system packaging and testing problems for unique vehicle models. Also, if a manufacturer had unique safety concerns on one or two body lines/styles, this approach would offer a manufacturer more leadtime to properly address them. In addition, it could improve the cost efficiency of controls by allowing manufacturers to forego development of onboard systems for vehicle models scheduled for retirement or permit manufacturers other flexibilities with new models being planned and those now in production. The implementation of other unique control strategies, such as bladder systems, would require more leadtime.

It is also important to note that if onboard controls are required, the date of promulgation of the final rule may be such that more than 24-months leadtime is actually available. The model year generally begins in September or October. If the publication of the final rule is much beyond that period, the manufacturers would have the remainder of that model year in addition to the 24 months discussed previously. Therefore, in actuality manufacturers could have substantially more than 24 months, but EPA's analysis indicates that only 24 months is needed.

In conclusion, given the magnitude of the task, this analysis indicates that 24 months of leadtime is adequate to allow manufacturers to safely and effectively implement onboard controls. This estimate is supported by EPA's experience with implementing evaporative emission standards and NHTSA's experience with implementing the various versions of FMVSS 301. However, EPA is committed to providing the leadtime necessary to implement onboard controls both safely and effectively. Thus EPA is open to considering more leadtime and/or a short phase-in period or other approaches which are pertinent.

Up to this point, this report has addressed onboard safety issues from primarily a passenger car and light truck point of view. It should be noted however that just as evaporative emission control technology was extended to heavy-duty gasoline fueled vehicles (HDGVs), onboard control technology could also be applied to HDGVs. While many of the safety issues discussed thus far would be identical in an HDGV application, some aspects of HDGV onboard safety would be distinct from light-duty issues. The next section in this report has been included to address the similarities and differences between heavy-duty and light-duty onboard safety issues.

VII. Heavy-Duty Gasoline Vehicle Requirements

Since an EPA onboard refueling control requirement would cover heavy-duty gasoline vehicles (HDGVs), in addition to passenger cars and light trucks, it is important to evaluate any potential HDGV onboard system safety considerations as well as those encountered in light-duty applications. (It is important to note that an onboard requirement will not apply to heavy-duty diesel trucks and buses.) While none of the comments received regarding the safety implications of onboard specifically addressed HDGVs, overall light-duty concerns discussed earlier are expected to apply. However, it is important to note that HDGV fuel system configurations differ somewhat from those found on passenger cars and light trucks, and the fuel system safety requirements also differ.

This section of the report identifies distinct HDGV onboard safety issues and discusses the implications these distinctions could have on manufacturers fuel system safety designs. It begins with a brief description of some of the more common HDGV configurations. Following these descriptions, a discussion of the HDGV fuel system safety standards will be presented, and differences between light- and heavy-duty vehicle onboard systems due to fuel system configurations and safety test requirements will be discussed. Next, HDGV onboard safety issues will be introduced and analyzed. Finally, this section will end with a brief segment concerning the effect of HDGV onboard safety on costs and leadtime.

Before beginning this analysis one key clarification is needed. FMVSS 301 covers all vehicles with a gross vehicle weight rating (GVWR) of 10,000 lbs or less (plus school buses over 10,000 lbs GVWR). For emission control purposes EPA classifies all gasoline-powered vehicles with a GVWR of 8,501 lbs or more as HDGVs. Out of EPA's HDGV category only 90,000 vehicles (or approximately 25 percent) have a GVWR greater than 10,000 lbs. Thus most (or approximately 75 percent) of EPA's HDGV class (those vehicles with a GVWR between 8,501 and 10,000 lbs-Class IIb) is covered by the LDT requirements in FMVSS 301. Since the fuel systems on Class IIb HDGVs are essentially identical to those on lighter weight LDTs, and FMVSS covers all LDTs up to 10,000 lbs GVWR, the previous portion of this analysis applies to the Class IIb HDGVs. The remainder of this analysis will focus on gasoline-powered vehicles whose GVWR exceeds 10,000 lbs.

This analysis addresses compliance costs with the assumption that HDGV manufacturers will use only certified fuel tanks on their vehicles. Currently, it is the owner's responsibility to purchase and use a certified tank if required by regulation. The current Motor Carrier Safety Regulations exempts a vehicle or driver used entirely within a municipality or commercial zone, although they may voluntarily comply with the regulations. These regulations may be changed in the future to be applicable to all HDGVs and eliminate the aforementioned commercial zone exemption. Therefore, this analysis assumes that all HDGVs will use fuel tanks certified to comply with the regulations discussed below.

A. HDGV Fuel System Configurations

Just as there are chassis and drivetrain differences between heavy and light-duty vehicles, there are also some differences in their fuel system configurations. Fuel tanks are generally of a heavier construction and are larger in volume; dual fuel tanks are also more common. Fuel tank shapes vary somewhat as does the location of the tanks on the vehicle. Also, it is often the case that the fillpipe is integral with the fuel tank, or has a very limited length as compared to lighter weight vehicles.

As a part of a recent contract study, EPA surveyed the characteristics of the fuel/vapor handling systems of HDGVs over 10,000 lbs GVWR.[41] The key results of the survey portion of that report are summarized in Table 5, which will serve as the basis for the remainder of this discussion.

Table 5

Selected Characteristics of Heavy-Duty Gasoline Vehicle Fuel/Vapor Handling Systems by Vehicle Model/Series

Manufacturer	Model or Series	Fuel Tank Shape	Fuel Tank Location	Number of Canisters	Size of Canisters	Diameter of Vent Lines	Diameter of Purge Lines
GM	P4T042	Rectangular	30 gal. Mount On Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
	P6T042	Rectangular	30 and 60 gal. Mounted on Left Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
	C5D042	Rectangular and Rectangular Step	20 gal. Mounted Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
			50 gal. Step Mounted Right or Left Hand Frame				
	C6D042 C7D042 C7D064	Rectangular and Rectangular Step	20 gal. Mounted Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
			50 gal. Step Mounted Right or Left Hand Frame				
			Dual 50 gal. Step Mounted Left and Right Hand Frame				
	B6P042	Rectangular	30 gal. Mounted Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
			60 gal. Mounted Right Hand Frame				
FORD	F-Series	Rectangular	35 gal. Right Hand Side Frame Mounted	2	1400 ml. ea.	3/8 in.	3/8 in.
	B-Series	Rectangular	30 gal. Right Hand Side Frame Mounted	2	1400 ml. ea.	3/8 in.	3/8 in.
	C-Series	D-Type	50 gal. Right Hand Side Frame Mounted	2	1400 ml. ea.	3/8 in.	3/8 in.

First, as can be seen in Table 5, there are only two manufacturers which market HDGVs. Between them they offer only about 10 different chassis models to which any number of different bodies or payloads can be attached (tanks, dumps, cargo boxes, motor homes, school buses, flat beds, etc).

The second area of interest is the fuel tanks. Essentially three different tanks shapes are used: standard rectangular, step rectangular, and D-shape. Examples of these tanks are shown in Figure 24. The tank volumes range from 20 gallons to 60 gallons, with an average in the range of 35 to 40 gallons for single tank HDGVs and 75 gallons for dual-tank HDGVs. EPA estimates that about 15 percent of HDGVs use dual tanks, with most of those being in heavier weight trucks (>20,000 lbs GVWR).[17] Most passenger car and light truck fuel tanks are located under the vehicle body and this is also the case for some HDGV configurations (e.g., school buses). However, on some HDGV configurations, the fuel tanks are mounted on the outer side of the vehicle frame (right or left hand side for single tanks, both sides for dual tanks) and are exposed to the road rather than shielded by the vehicle body. As was alluded to above, most HDGV tanks have only a limited fillpipe length (<8") and some have essentially none at all, with the fuel cap being integral to the tank.

Finally, with regard to the HDGV evaporative emission systems two observations are important. (See Figure 25 for an example of a HDGV evaporative system.) First, for the same reasons as described for passenger cars and light trucks, HDGVs use a limiting orifice in the evaporative emission system. Second, the total evaporative emission canister capacity on an HDGV is more than twice the average on passenger cars and LDTs (2.8-4.0 liters). However, on HDGVs diurnal emissions from the fuel tank and hot soak emissions from the fuel metering system are routed to different canisters. Hot soak emissions are somewhat more of a concern on HDGVs because presently most are carbureted rather than fuel injected. To the degree that HDGV engines fuel systems are converted from carbureted to fuel injected as is now projected, concerns over hot soak emissions may diminish and allow the elimination of the second canister on those vehicles.[42,43]

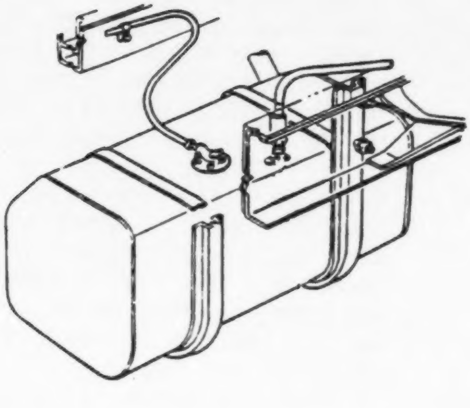
With this brief background on HDGV fuel/evaporative systems we turn now to a discussion of the fuel system safety standards which apply to HDGVs over 10,000 lbs GVWR.

B. HDGV Fuel System Safety Standards

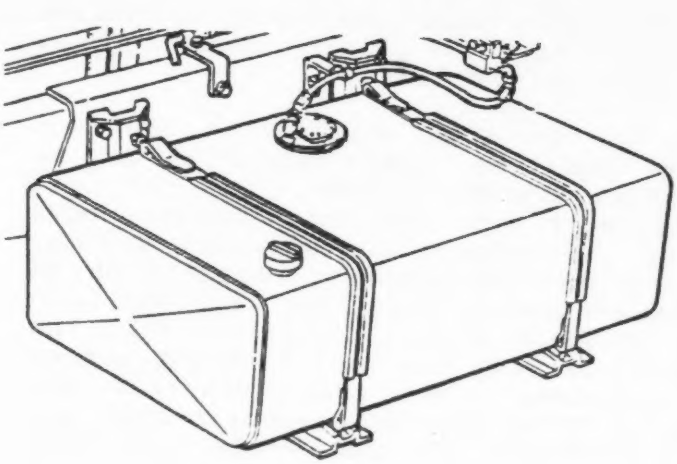
Fuel system safety regulations differ according to vehicle and fuel system configuration. The Department of Transportation/Office of Motor Carrier Safety (OMCS) has requirements which apply to all HDGVs over 10,000 lbs GVWR. In addition, school buses must meet the requirements prescribed specifically in FMVSS 301. The OMCS and FMVSS 301 requirements are summarized below.

Figure 24

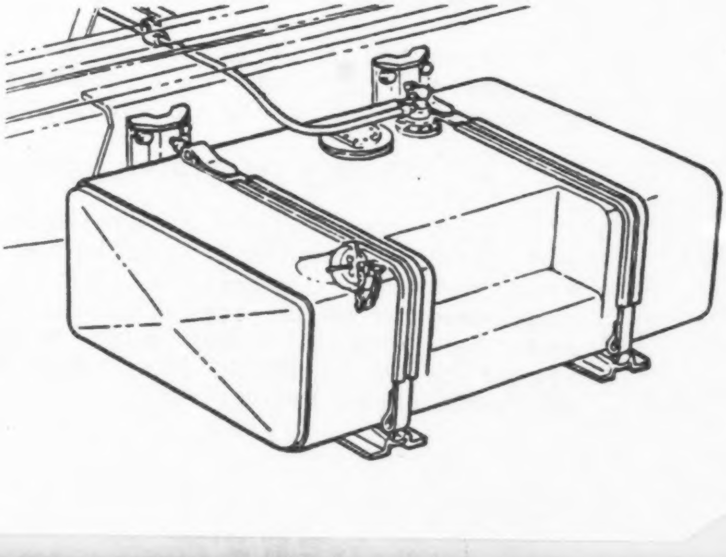
HDGV Fuel Tanks



D-Shape



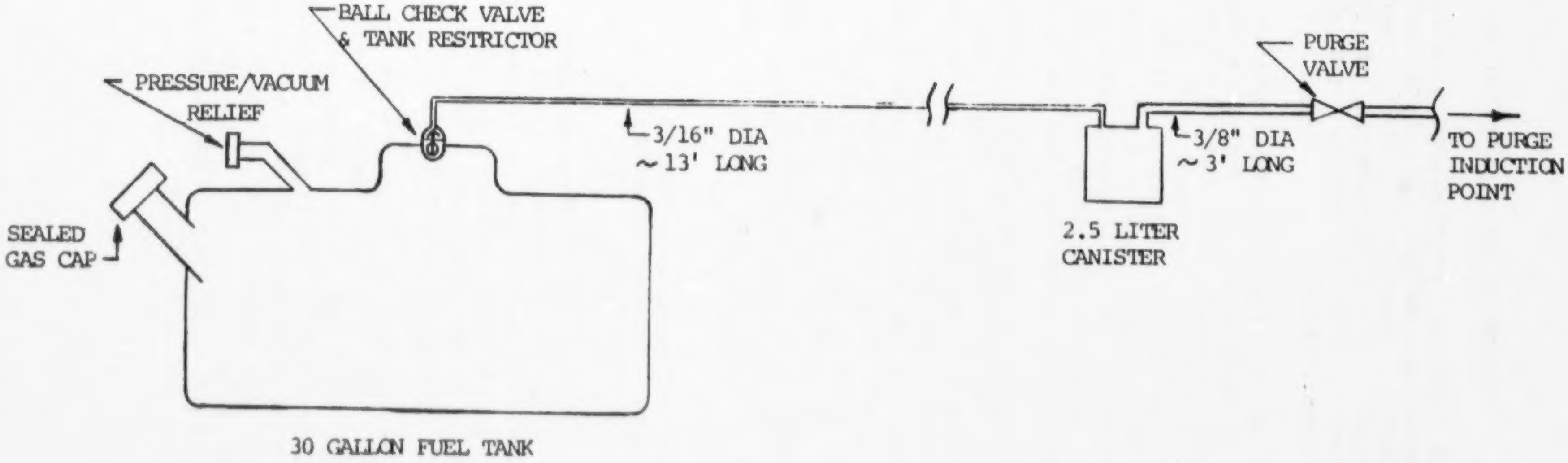
Standard Rectangular



Step Rectangular

Figure 25

TYPICAL HDGV EVAPORATIVE SYSTEM


BALL CHECK VALVE
& TANK RESTRICTOR
PRESSURE/VACUUM
RELIEF
SEALED
GAS CAP
3/16" DIA
~ 13' LONG
30 GALLON FUEL TANK
PURGE
VALVE
3/8" DIA
~ 3' LONG
2.5 LITER
CANISTER
TO PURGE
INDUCTION
POINT

1. Office of Motor Carrier Safety Requirements

OMCS safety regulations include both specific design requirements and actual fuel tank safety tests.[44] The design requirements contain rules governing the location, installation, and construction of fuel tanks used on HDGVs. Also, fuel lines, fittings, and fillpipes must conform to certain requirements.

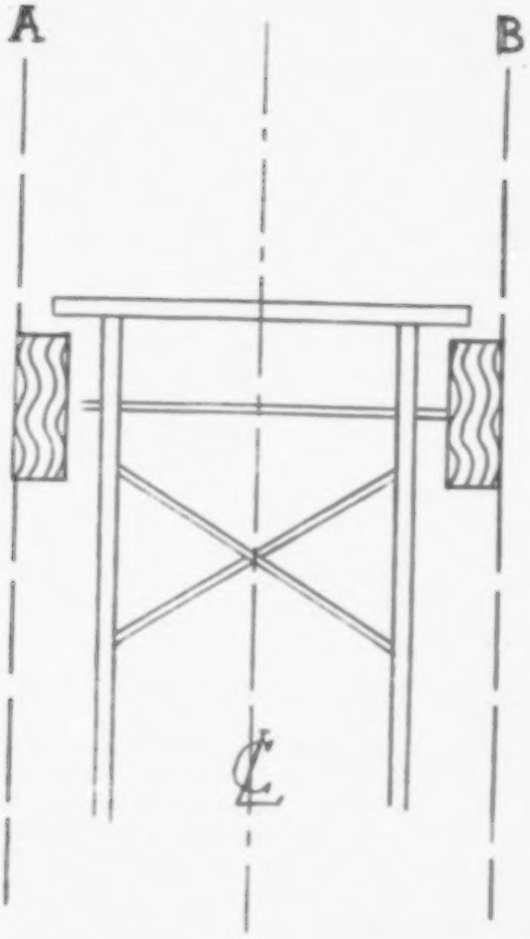
The actual testing requirements depend on whether a fuel tank is side-mounted or non-side mounted. To paraphrase the definition, a truck fuel tank is considered side mounted if it extends beyond the outboard side of a front tire positioned in the straight ahead position. This is shown pictorially in Figure 26. Any fuel tank which does not have this characteristic is considered non-side mounted, and in this analysis will be referred to as frame mounted. The testing requirements for frame-mounted tanks will be discussed first.

A frame mounted HDGV fuel tank has to be able to pass two fuel tank safety tests. The first of these two tests, the safety venting system test, involves applying an enveloping flame to an inverted fuel tank to insure that the fuel tank's safety venting system activates prior to the tank's internal pressure exceeding fifty pounds per square inch. The second fuel tank safety test is a leakage test which involves filling the tank to capacity and rotating the tank through an angle of 150° in any direction from its normal position to insure that neither the tank nor any fitting leak more than one ounce of fuel per minute in any position the tank assumes during the test.

HDGVs with side mounted fuel tanks must pass two other tests which involve dropping the fuel tank to test impact resistance. The first test, termed the drop test, involves dropping a fully loaded (equivalent weight of water) tank from 30 feet onto an unyielding surface, so that it lands squarely on one corner. A second similar test (termed the fillpipe test) requires that a fully loaded tank be dropped from 10 feet onto an unyielding surface, so that it lands squarely on its fillpipe. In neither case, may the tank nor any fitting leak more than one ounce per minute.

Based on conversations with the two HDGV manufacturers, the vast majority of HDGV fuel tanks are frame mounted (non-side mounted). No side mounted tanks are offered as standard equipment, and only occasionally one is sold as a special order.[45,46] Thus, this analysis will focus primarily on the safety venting and leakage test requirements which apply to frame mounted tanks. However, the drop tests for side mounted tanks will also be considered.

Figure 26



Pictorial Definition of Side-Mounted Fuel Tank.
If the tank extends to the left of line A or to the right of line B, then the tank is side-mounted. Lines A and B are tangent to the outer sides of the front tires.

2. School Bus Requirements

In addition to the OMCS requirements for frame-mounted tanks, outlined above, school buses are required to meet specific FMVSS 301 standards. However, this coverage does not include all of the test requirements as prescribed for passenger cars and light trucks. FMVSS 301 for school buses over 10,000 GVWR requires an impact with a contoured moving barrier at any speed up to and including 30 mph, at any point and angle. Depending on the design and location of the fuel tank and its protective structure, the "worst case" point and angle of contact is determined for each school bus model, and the contoured moving barrier impacts there. In this test, the fuel system must be designed so as not to leak more than one ounce of fuel per minute.[47]

This briefly summarizes the current Federal safety standards applicable to fuel systems on HDGVs over 10,000 GVWR. It is important to note that more safety requirements could be applied to HDGVs over 10,000 GVWR in the future. The Department of California Highway Patrol recently submitted a petition to NHTSA to amend FMVSS 301 to include fuel system integrity testing for heavy-duty vehicles over 10,000 GVWR.[48] With this background information we are now prepared to discuss how the differences in vehicle/fuel system configurations and the Federal safety standards may affect the design of an onboard system for an HDGV relative to the design for passenger cars and light trucks.

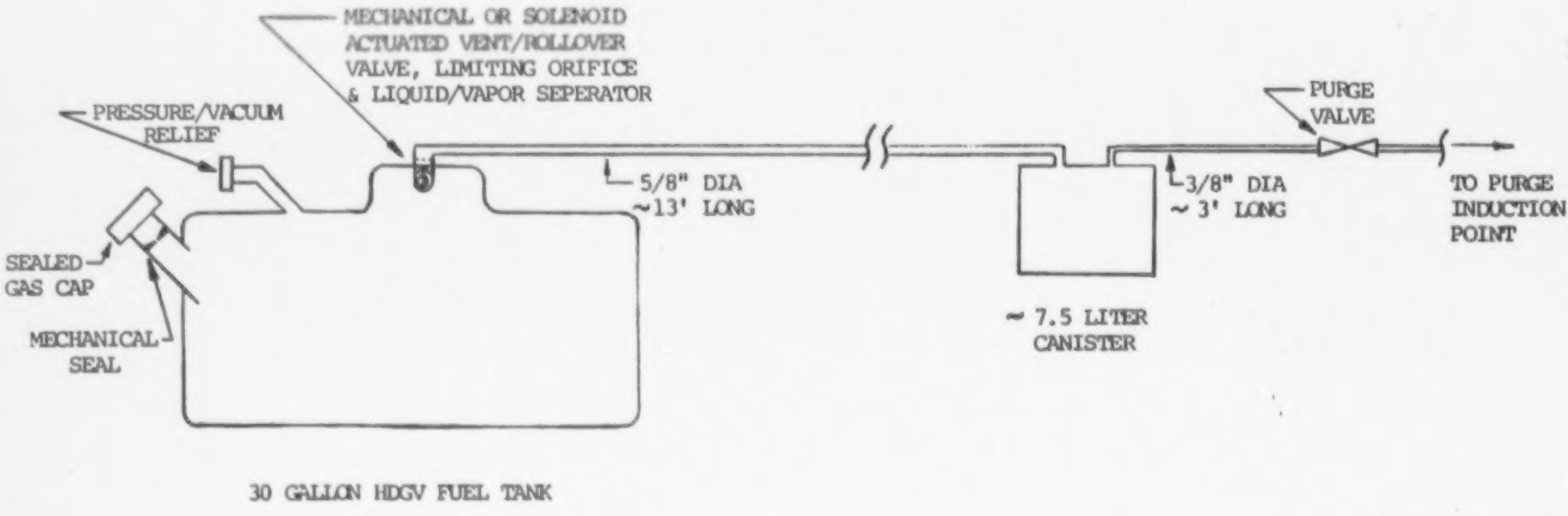
C. Distinctions in HDGV Onboard Systems

Just as the evaporative emission control systems used on HDGVs are very similar to those used on passenger cars and light trucks, it is also expected that an HDGV onboard system would be very similar in design and approach to that conceived for lighter-weight vehicles (a possible HDGV onboard system is shown in Figure 27). However, some minor variations would exist due to differences in HDGV fuel system configurations and the requirements levied by the applicable Federal safety standards. Before beginning a discussion of these minor variations, it is valuable to reiterate a few key points raised previously with regard to the magnitude of the task of implementing onboard controls.

First, like passenger cars and light trucks, all HDGVs now incorporate evaporative emission control systems (see Figure 25) and their fuel systems must meet the present Federal fuel system integrity standards (OMCS and NHTSA). Thus, as before with the lighter weight vehicles, the application of onboard systems is best evaluated incrementally to the measures already taken to incorporate evaporative emission controls and meet safety standards. Much of the ground work has already been completed, the needed modifications made and components added.

Figure 27

POSSIBLE HDGV INTEGRATED EVAPORATIVE/REFUELING SYSTEM


MECHANICAL OR SOLENOID ACTUATED VENT/ROLLOVER VALVE, LIMITING ORIFICE & LIQUID/VAPOR SEPERATOR
PRESSURE/VACUUM RELIEF
SEALED GAS CAP
MECHANICAL SEAL
5/8" DIA ~13' LONG
~ 7.5 LITER CANISTER
3/8" DIA ~ 3' LONG
PURGE VALVE
TO PURGE INDUCTION POINT
30 GALLON HDGV FUEL TANK

In many cases no changes to present fuel system safety assurance or evaporative emission control measures will be needed. Second, it is important to note that HDGV onboard refueling and fuel tank evaporative emission control systems will likely be integrated as with lighter weight vehicles. This is quite easy to accomplish on HDGVs, since they now have separate canisters and control systems for fuel tank and fuel metering system evaporative emissions. Thus a whole new system will not be added to control HDGV refueling emissions; instead the refueling and fuel tank evaporative emission control systems will be integrated into one (compare Figure 25 with Figure 27). Thus many of the primary design considerations which applied for the evaluation of onboard systems to passenger cars and light trucks also apply to HDGVs.

Remembering the expected similarities between light and heavy-duty vehicle onboard systems and that the factors affecting the implementation are also the same, the expected minor variations in HDGV onboard systems can now be discussed. For sake of presentation, discussion will begin at the fillpipe and follow along the system to the canister. The analysis will assume an integrated onboard refueling/fuel tank evaporative control system as discussed above.

To begin with, because the fillpipes on HDGV fuel tanks are either relatively short or integral with the tank, liquid fillneck seals which require an appreciable fill height may not be a practical approach in some configurations. Due to this lack of fill height, HDGV manufacturers might elect to utilize a mechanical seal approach and thus would need to incorporate some type of pressure relief device such as was described previously. HDGV fuel tanks, which are made of steel or aluminum, now use a pressure-vacuum relief valve, and it is conceivable manufacturers will simply modify that valve for this application. However, under the proper backpressure conditions, it might be possible to use a liquid fillneck seal by extending the fillpipe horizontally in the tank as has been demonstrated in a prototype light-duty program.[15]

A second potential difference lies in the diameter of the refueling vapor line and related fuel tank vent. From a design perspective, the tank vent and refueling vapor line size (diameter) could be affected by the fuel dispensing rate. As part of the refueling emissions test procedure, EPA is proposing that HDGV fuel systems be designed for refueling at a maximum rate of 10 gallons per minute, the same rate as prescribed for other vehicles.* This 10 gallon per minute dispensing rate results in an increase in the current orifice and evaporative vapor line diameter from about 3/8 inch to about 5/8 inch for an HDGV onboard system.

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* Discussions with gasoline marketing interests and nozzle manufacturers indicate that gasoline available to passenger cars, light trucks, and HDGVs (either at retail or private pumps) is normally not dispensed at rates greater than 10 gpm.

However, to minimize spillage during refueling, the OMCS has requirements that any liquid fuel tank over 25 gallons in capacity must be able to accept fuel at a rate of 20 gallons per minute.[49] For an onboard system this requirement could lead to a increase in the diameter of the tank vent outlet and refueling vapor line. It should be noted, however, that while this requirement applies to all heavy-duty liquid fuel tanks (both diesel and gasoline), fundamentally it is aimed more at diesel fuel tanks. It is not uncommon to encounter an in-use diesel fuel dispensing rate of 20 gpm or more to reduce the time needed to fill a diesel tank since these tanks are typically much larger than gasoline tanks and dual diesel tanks are also more common.[50] In-use gasoline dispensing rates on the other hand normally do not exceed 10 gpm. Since in-use gasoline dispensing rates usually do not exceed 10 gpm, and EPA's refueling certification test would involve a 10 gpm maximum dispensing rate, OMCS's requirement in this area may not be needed. EPA has discussed this matter with DOT/OMCS, and they have expressed a willingness to consider changing this requirement to apply only to diesel fuel tanks.[51,52] If this standard is not changed, and a 10 gpm dispensing rate limit is enacted, the only affect would be that the refueling vent orifice/line for these vehicles would be over sized.

Nevertheless, because HDGV fuel tanks do not use long fillnecks, fuel dispensing operations would not be as sensitive to higher backpressure as they would be in light-duty. Even if the refueling vent orifice/line were sized for a 10 gallon per minute dispensing rate, fuel could be dispensed at a greater rate without premature shutoffs. Thus it may not be necessary to size the refueling orifice/vent line to match the dispensing rate requirements. However, in optimizing system designs with regard to fuel tank pressure, manufacturers may choose to use a slightly larger refueling vent orifice than seen on light-duty applications.

One final manner in which HDGV onboard systems might differ from those on lighter weight vehicles is in the design of the rollover protection device. The solenoid activated rollover valve (Figure 19) or the combination valve (Figure 21) could be applied to HDGV fuel tanks in their present configurations. One manufacturer's fuel tank design now incorporates a ball type check valve similar in principle to the combination valve.[41] Also, the nozzle actuated valves shown in Figures 9-15 could also be used on HDGV fuel tanks which have a fillpipe length of 6 inches or more. However, nozzle actuated valve designs would have to be modified slightly to perform on fuel tanks whose fillneck is essentially integral with the tank. Nonetheless, the basic approach and operation would be the same.

Any of the three rollover valve designs mentioned above could be used on HDGV fuel tanks. However the best choice for any tank would depend on the fillpipe length or other trade-offs relative to cost, packaging etc. With proper design and integration any of these valve designs could provide rollover protection in-use.

With this background on HDGV fuel system configurations, safety requirements, and HDGV onboard system characteristics, it is now possible to address some of the unique safety concerns related to HDGV onboard. The next segment of this report discusses and addresses potential impacts of HDGV onboard on fuel system safety considerations.

D. HDGV Onboard Safety Issues

1. Introduction

While none of the comments received regarding the safety implications of onboard controls specifically addressed HDGVs, it is reasonable to expect that overall concerns would be similar because of the expected close resemblance between light and heavy-duty vehicle onboard systems. To avoid repeating much of what has previously been discussed, this segment will primarily focus on unique HDGV onboard safety considerations. The analysis presented in Section IV regarding maintenance, repair, tampering and defects and refueling operation safety apply equally to HDGVs and will not be repeated here. The potential problems are similar and the same basic approach and straightforward engineering solutions can be used. Also, the extensive analysis in Section V regarding in-use fuel system safety also applies to HDGVs. As before, manufacturers are expected to manage risk appropriately; there is no reason that adding an onboard system would directionally increase in-use risk over that now accepted with present HDGV fuel/evaporative emission systems.

However, as was discussed above the fuel system configurations and the safety test requirements for HDGV fuel tanks are somewhat different from light-duty, so some discussion of distinct safety test design requirement issues is appropriate.

2. Safety Test Design Requirements

As mentioned above, there are two separate areas of safety test design considerations for HDGV fuel systems. The Office of Motor Carrier Safety (OMCS) has fuel system safety regulations which apply to all HDGVs, and NHTSA has additional requirements for school buses. This segment begins with a summary and analysis of safety design considerations related to OMCS requirements. Following this is a discussion of the effects of NHTSA's crash test requirements.

a. OMCS Requirements/Considerations

OMCS has established fuel system requirements for HDGVs to insure their structural and in-use integrity. As part of the current requirements, HDGV fuel tanks must be capable of passing the safety venting system and the leakage tests described previously. Currently HDGV fuel tanks employ a ball check valve and pressure vacuum relief valve to pass these two tests. Since the refueling vent orifice would be somewhat larger with an onboard system (5/8") the ball check valve would have to be upgraded to provide the necessary protection. Little or no change to the pressure vacuum relief valve would be needed.

For an HDGV onboard system, the protection now supplied by the ball check valve could be supplied by the rollover valve designs described previously. The same three general types of rollover protection devices that were discussed for use in light-duty applications (nozzle actuated, solenoid, and mechanically activated valves) would all be feasible in various heavy-duty applications as well. However, for tanks with little or no fillpipe (<6") the nozzle actuated valve design would probably have to be modified slightly and mounted in the tank instead of on the fillneck. A solenoid or mechanical rollover (ball) valve design could essentially be used as shown earlier.

HDGV and light-duty onboard systems would be functionally identical and would be very similar in design and configuration except for canister size and vapor line length. Of course, to meet safety requirements and to provide in use protection, manufacturers will have to consider the structural integrity and the materials used in key system components just as they do now with other components of the fuel/evaporative system. Thus, some components of the HDGV onboard system (notably the rollover valve) may need to be constructed of metal to provide impact resistance and the flammability protection demanded in the safety venting test.

Also, with regard to impact resistance, any one optional side-mounted tank model, would be subject to two additional safety tests (drop tests) designed to evaluate the tank's impact resistance. A side-mounted fuel tank would likely utilize a rollover valve mounted integral to or within the tank to insure its integrity during the drop tests. While this would not be difficult to design (many current fuel tanks contain interior components), it would represent an additional design consideration for side-mounted fuel tanks. From an in-use safety perspective, the impact resistance and overall integrity of rollover valves on frame mounted tanks would be enhanced if they were mounted integral or internal to the tank. Thus, this approach would be attractive for all HDGV fuel tanks.

In conclusion, the only HDGV onboard safety design feature introduced by the need to meet OMCS safety requirements is the upgrade of the current rollover protection device. All of the rollover protection approaches discussed for light-duty applications (nozzle actuated, solenoid, or mechanically activated valves) could be used to meet this requirement. The design, placement, and construction of the rollover valve on a particular HDGV fuel tank would depend in part on fillpipe configuration, impact resistance concerns, and flammability potential.

b. NHTSA Requirements/Considerations

In addition to OMCS requirements, all school buses over 10,000 lbs. GVWR must also meet specific requirements of NHTSA's FMVSS 301. As described earlier, this involves a single moving contoured barrier test at a maximum of 30 mph and does not include a rollover test. In this test, the barrier impacts the school bus at the most vulnerable location of the fuel tank, and the fuel system must be designed so as not to leak more than one ounce of fuel per minute. As was true of OMCS requirements, an acceptable school bus onboard system is one which does not impair the fuel tank's ability to meet this requirement.

As in the light-duty test, the crashworthiness of all the onboard system components (rollover valve, charcoal canister, critical vapor line and vapor line connections between the top of the fuel tank and the rollover valve) would all be evaluated in the test. Design measures similar to those described for passenger cars and light trucks would have to be taken to assure the integrity of these three key components.

The crashworthiness discussion in Section IV-A and the further options discussed in Section V addressed specific safety design approaches for these components which could also be applied to school buses, so this will not be addressed further. As before with light-duty applications, evaporative emission systems provide directly relevant techniques and experience to assist in proper design, and specific engineering measures have been suggested to deal with potential concerns.

Furthermore, the in-use safety of onboard refueling controls for HDGVs must be considered. The location of onboard system components, as with the current fuel tank and evaporative emission controls, must minimize any potential safety risks. Much of the HDGVs fuel system damage seen today is caused by foreign objects from the road surfaces. Therefore, critical onboard control system component should be located on the HDGV in a position which will minimize any foreign object damage.

In conclusion, HDGV onboard systems do not introduce any new or significant problems to manufacturers' attempts to design safe fuel systems capable of meeting NHTSA and OMCS safety requirements. Straightforward, viable engineering solutions are available to address all problems that have been identified. Therefore, onboard systems are expected to be integrated into HDGV fuel systems without reducing the system's ability to meet all applicable Federal safety requirements.

3. Summary

As was mentioned in the light-duty section of this report, EPA's philosophy in evaluating the safety implications of requiring onboard controls (including those for HDGVs), is that no increase in overall risk should be caused or accepted, beyond that now present with today's fuel/evaporative system. This applies to both compliance with the applicable Federal Safety standards and the in-use safety of vehicles equipped with onboard systems. This portion of the analysis has addressed the safety test design requirements related to implementing HDGV onboard systems, and as was the case for light-duty it concludes that straightforward engineering solutions are available for all of the potential safety problems which have been identified, and safe fuel system designs are achievable by all.

E. Cost and Leadtime Considerations

EPA has received no comments which directly address specific HDGV onboard safety cost and leadtime implications. However, an analysis of the costs and leadtime necessary to implement HDGV onboard controls safely is an integral part of the overall evaluation of the feasibility of this control approach. The first portion of this section addresses HDGV onboard safety costs; the second discusses HDGV leadtime requirements and describes the basis for EPA's leadtime estimates. Some of the cost figures cited in the safety cost analysis are drawn from a broader EPA analysis which develops total HDGV onboard system costs in 1984 dollars.[17]

1. Safety Costs

As was true of light-duty onboard safety costs, the costs needed to implement HDGV onboard controls fall in several areas. R&D type costs will be incurred, some new or modified components will be needed which may slightly affect vehicle operating costs, and safety certification testing will be necessary. However, before beginning a discussion of these costs, it is valuable to discuss how EPA's HDGV evaporative emission control requirements impact onboard safety costs.

As was described in the light-duty section of the report, an onboard system (even those for HDGVs) is in many ways an extrapolation of current evaporative emission control technology and the two systems are quite similar. Since onboard systems are basically extensions of evaporative emission systems, clearly many of the safety design considerations associated with onboard systems related to meeting OMCS/NHTSA requirements or providing in-use assurance have already been addressed in evaporative emission system designs. Consequently, much of the ground work required to insure onboard safety has already been performed. It is important to keep the magnitude of the HDGV onboard safety design process in perspective, because much of the safety technology needed is simply an extension of that which already exists. Noting the "incremental" nature of onboard safety in terms of the magnitude of the task and actual cost relative to evaporative systems, it is now possible to describe the components which factor into onboard safety costs.

Basically, the integration of safety into a fuel system incorporating an onboard system involves four types of costs. These four costs are for: 1) design and development (R&D), 2) specific hardware, 3) safety testing, and 4) weight penalty (or added fuel consumption). The paragraphs that follow describe how each of the cost components are affected by onboard safety.

To begin with, some research and development will have to be performed to safely integrate onboard controls into HDGV fuel systems. EPA has estimated that the total design and development cost required to incorporate onboard systems in HDGV fuel systems is about $34,200 per family or $1.50 per vehicle (over 10,000 lbs GVWR). This cost is for any development effort involved in combining the components of an onboard system with the rest of the vehicle to form a unit that interacts safely and effectively. Because safety is evaluated inherently in the design and development process and yet is only one part of the total effort, only a fraction of the total cost should be directly allocated to safety. The light-duty cost section explained why this fraction is likely to be small. The same reasoning is also applicable for heavy-duty applications, and therefore it was assumed that about 20 percent of R&D expenditures relate to safety, which translates to about $0.30 per vehicle.

The second component of HDGV onboard safety costs relates to specific hardware that may be required to insure fuel system safety. EPA has estimated costs for three specific items which have been identified as potential components to be included as part of the onboard system design explicitly for safety reasons. These three items are 1) a rollover valve, 2) a pressure relief mechanism, and 3) fuel system modifications necessary to safely incorporate a rollover valve, pressure relief mechanism, or other onboard hardware. HDGV rollover valves should not differ in cost from light-duty valves since they would essentially be the same. Therefore, the light-duty estimate of $3.00 to $6.00 will also be used here.

The second safety hardware cost is for a pressure relief mechanism. Since this mechanism would be needed for onboard systems incorporating a mechanical fillneck seal, many HDGVs would require its use. EPA's analysis prices this device at $2.50.[13] At this point, this estimate is considered to be very conservative, since the possibility exits that the present pressure relief device can be modified to perform this function.

The final onboard safety hardware cost accounts for any fuel system modifications that would be necessary in order to safely accommodate any onboard control hardware. For example, a HDGV fuel tank or fillpipe might have to be re-shaped or modified in order to accept a rollover valve. Also, some slight re-routing of the fuel system's vapor lines may be required. EPA has estimated a total modification cost to be $0.50 per fuel tank. Only part of this total cost would be required for safety purposes. However, because safety inherently enters into the decision to make any modifications, it is difficult to access what part of the total modification cost should be allocated to safety; perhaps half ($0.25 per fuel tank) could be considered as driven by safety related concerns.

Summing up the three individual safety hardware costs per fuel tank yields a total estimated figure in the range of $5.75 to $8.75. However, this cost estimate does not include manufacturer overhead and profit. Consequently, in order to obtain the retail price equivalent cost, these estimates must be multiplied by a markup factor. Presently, a markup factor value of 1.27 appears representative.[37] Therefore, after integration of the markup factor, a total retail price equivalent HDGV safety-related hardware cost per fuel tank falls within the range of $7.30 to $11.10. Since 15 percent of HDGVs have dual tanks, the total HDGV safety-related hardware cost range is $8.40 to $12.80

The third component of safety costs is for any safety testing that would be necessary. Unlike light-duty test costs, EPA has not thoroughly investigated HDGV safety test costs. However, safety test costs were estimated in an attempt to determine the approximate magnitude of the per vehicle HDGV safety test cost. Table 6 shows that even when fairly liberal safety test costs are assumed, the resulting cost/vehicle of $0.70 is very minimal in the long term.

The fourth component of safety costs is the estimate of the added fuel consumed over the life of the vehicle due to the increase in vehicle weight resulting from added safety hardware. The amount of weight added to vehicle from a

Table 6

HDGV Fuel Tank Safety Test Costs Estimate

1. OMCS Requirements:

   2 tests per HDGV fuel system configuration
   (Safety Vent Test and Leakage Test)

   Conservative Cost/Test Estimate: $2,000

   8 HDGV Fuel Tank Configurations

   Total OMCS Safety Test Cost: $32,000

2. NHTSA Requirements:

   1 test per HDGV fuel system configuration
   (30 mph moving barrier)

   Conservative Cost/Test Estimate: $30,000

   7 School Bus Configurations (7 manufacturers, 1 config./manufacturer)

   Total NHTSA Safety Test Cost: $210,000

3. Total HDGV Fuel Tank Safety Test Cost: $242,000

4. Cost/Vehicle (Amortized at 10 percent over 5 years of vehicle sales*): $0.70

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* Assumed that all bus manufacturers will crash test their vehicles.

** Vehicle sales were estimated at 90,000/year.

rollover valve or pressure relief mechanism is very small (0.4 lbs), and because HDGVs are less sensitive to weight changes than lighter weight vehicles, on average less than $0.30 in added fuel costs will result from their inclusion into the HDGV onboard system.[24]

A total onboard safety cost is calculated by summing all four individual component costs. Total safety-related onboard costs per family average about $270,000, and the per vehicle costs range from $9.70 to $14.10 or about 20-25 percent of the total cost depending on the type of rollover valve used.

2. Leadtime

If EPA were to implement an HDGV onboard requirement, it would be necessary to allow manufacturers enough leadtime to adequately prepare for the requirement. The HDGV preparation process would involve the same individual tasks that would enter into the light-duty process: system design, development, testing, tooling, certification, and safety evaluation. Although two of these leadtime tasks (certification and safety evaluation) would involve somewhat different procedures for HDGVs, they will essentially require the same amount of time and would factor into the total process in the same manner as in light-duty. Therefore, it is estimated that 24 months would be the total amount of leadtime required by HDGV manufacturers, and Figure 25 which shows the parallel/sequential progression of the individual leadtime components would be essentially the same for HDGVs.

Of the various leadtime components shown in Figure 25, all but two would be essentially the same for HDGVs as they would for light-duty applications. These two are certification and safety evaluation. In both cases, the HDGV processes appear as though they would take less time to complete than their light-duty counterparts because these tasks would be likely to be less difficult to perform. For example, in some cases, durability assessments for certification of HDGVs does not require any actual vehicle testing; bench evaluations can be substituted based on the manufacturers engineering judgment. This could save considerable time.

As far as safety evaluation goes, HDGV fuel tank tests performed to meet OMCS requirements would be much simpler to perform than NHTSA's safety crash tests for passenger cars and light trucks. Also, when NHTSA requirements do apply (as in the case of school buses) they only involve a single crash test with no rollover. (This is minor in comparison to tests which involve multiple crashes with rollover.) Therefore, the amount of time allowed for light-duty certification (10-12 months) and safety evaluation (>12 months) should also be sufficient for HDGVs since the heavy-duty processes are less involved. Overall, 24 months of leadtime for HDGV onboard is quite reasonable. This is especially true when one considers the development work already completed and the "incremental" nature of onboard in relation to current evaporative emission systems.

EPA's 24-month leadtime estimate is supported by past experience with previous HDGV evaporative emission rulemakings. These rulemakings include the California Air Resources Board original 1978 6.0 g/test HDGV evaporative emission standard which was implemented with just 21 months of leadtime.[53] The stringency of this standard was increased for 1980 model year HDGVs allowing only 2 g/test.[54] While this stricter standard was promulgated with 37 months of leadtime, manufacturers had to meet the 1978 standard first, which effectively limited the leadtime for the 1980 standard to about 24 months. One final evaporative emission standard which was implemented with 24 months of leadtime was EPA's 1985 HDGV standard. In each of these three rulemakings, manufacturers faced leadtime factors identical to the ones that would accompany an onboard requirement, including safety. Since manufacturers were able to safely and effectively integrate evaporative emission controls into their vehicle's fuel systems with 24 months of leadtime, and since the magnitude of the onboard implementation task is similar, manufacturers should also be able to safely and effectively integrate onboard into vehicle fuel systems with 24 months leadtime.

As far as safety development and evaluation is concerned, EPA's HDGV leadtime estimate is also supported by the past experience of OMCS and NHTSA in implementing various HDGV fuel system requirements. In 1973, OMCS extended its safety test requirements to include previously unaffected non-side-mounted (frame-mounted) HDGV fuel tanks. This requirement was implemented with just 18 months of leadtime.[55] Also in 1977, FMVSS 301 was extended to include school buses, and this requirement was implemented with 17 months of leadtime.[56] This experience indicates that 24 months of leadtime allows manufacturers sufficient time to factor in safety.

Based on the information provided above, it appears that 24 months is adequate time to implement HDGV onboard controls, with full consideration of all safety concerns. Because safety evaluation can proceed in parallel to three other tasks, more than a year is available for actual fuel tank safety tests, school bus crash testing, or any desired computer simulation. This allows adequate leadtime to properly integrate safety into HDGV onboard systems especially since manufacturers can utilize and expand safety technology used in current evaporative emission control systems to develop effective onboard systems. Also, much of the safety development which would be required has already taken place with the identification and resolution of such potential safety issues as rollover protection and fuel tank pressure relief. Consequently, a 24-month leadtime period would provide manufacturers with sufficient opportunity to develop safe and effective onboard systems.

While the current leadtime estimate of 24 months is reasonable for all vehicle models including HDGVs, EPA is sensitive to manufacturers concerns regarding leadtime requirements. EPA is committed to providing manufacturers the leadtime necessary to implement onboard controls safely and effectively. Designing safe onboard controls for some unique HDGVs may require more leadtime. Such HDGVs include those with atypical duty cycles, unique fuel tank or body configurations, and those HDGVs from secondary manufacturers. Consequently, EPA would include HDGVs as part of any overall consideration of additional leadtime or a short phase-in period for onboard controls.

F. Summary/Conclusion

The purpose of this section was to identify and address the potential effects onboard controls could have on a HDGV manufacturer's fuel system safety designs. After analyzing the potential safety concerns related to implementing HDGV onboard systems, EPA has found that like passenger cars and light trucks, heavy-duty onboard systems are extensions of current evaporative systems and corresponding safety considerations are similar in nature to those discussed for light-duty applications. While a few unique considerations do exist (in part because of differences in testing requirements, tank designs/locations, structural integrity, size etc.), no increase in overall risk should be caused or accepted, beyond that now present with today's HDGV fuel/evaporative system. This applies to both compliance with the applicable Federal safety standards and the in-use safety of HDGVs equipped with onboard systems. As was the case for light-duty, straightforward engineering solutions are available for all of the potential safety problems which have been identified, and that while final choices regarding exact system designs lie with the manufacturers, safe fuel system designs are achievable by all. EPA estimates that HDGV safety costs contribute about 20-25 percent of the total HDGV onboard system cost and should fall within the range of $9.70 to $14.10. With regard to leadtime, this analysis indicates that 24 months appears to provide HDGV manufacturers with adequate time to prepare for the safe and effective implementation of onboard controls, but as before with passenger cars and light trucks the possibility of the need for more leadtime for some vehicle models may exist.

VIII. Conclusion

EPA has investigated and analyzed each of the potential onboard system safety issues raised by the commenters. After carefully considering all of the potential impacts an onboard system could have on the overall safety of a vehicle's fuel system, it is concluded that straightforward, reliable, relatively inexpensive engineering solutions exist for each of the potential problems identified. Furthermore, no increase in risk need occur or be accepted because of the presence of an onboard system. Onboard equipped vehicles can be designed to pass FMVSS 301 and provide a level of in-use fuel system integrity equal to or better than that achieved on present vehicles which incorporate evaporative emission control systems. Of course final choices regarding exact onboard system designs lie with the manufacturers, and each manufacturer will choose the approach/system which provides the best balance of cost, safety, and other key factors. EPA would not adopt an onboard requirement unless it was clear that safe fuel system designs were available. This report demonstrates this to be the case. Safe fuel system designs are achievable by all manufacturers.

Furthermore, it it is quite possible that overall fuel system improvements could accompany the implementation of onboard controls and lead to a net improvement in the level of fuel system safety on in-use vehicles. For example, collapsible bladder tanks are one design option that could control refueling emissions, reduce evaporative emissions and at the same time improve fuel system safety.

Manufacturers can and are expected to design and implement onboard systems in a manner which provides at least the same level of fuel system safety as achieved on present vehicles. In addition, a number of design options and other measures are available with onboard systems, which suggest that fuel system safety in-use can be improved along with the incorporation of onboard control systems.

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